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THE APRIL SCIENTIFIC MONTHLY

EDITED BY J. MCKEEN CATTELL

CONTRIBUTIONS THAT HAVE BEEN MADE BY PURE SCIENCE TO THE ADVANCEMENT OF ENGINEERING AND INDUSTRY:

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THE SCIENTIFIC MONTHLY

APRIL, 1927

CONTRIBUTIONS THAT HAVE BEEN MADE BY PURE SCIENCE TO THE ADVANCEMENT OF ENGINEERING AND INDUSTRY[1]

By Dr. C. R. RICHARDS
LEHIGH UNIVERSITY

IT is, I think, safe to assert that those machines and processes which have revolutionized industry and the practice of engineering were originally evolved through accidental discoveries or pure invention; and that their later development has generally been based upon empirical knowledge. For a time empirical methods may be sufficient, but, sooner or later, every industry feels the need of precise knowledge of its processes or of its materials that can only be supplied through the aid of the fundamental sciences. No industry can feel secure until it is fully cognizant of the scientific basis upon which its activities depend, and that, through research in the fundamental as well as in the applied sciences, seeks to advance further its knowledge and improve its product.

The practice of engineering has been profoundly affected by the fundamental sciences, each of which in some manner has influenced the work of the engineer. In the practice of engineering it is no longer sufficient to work with rule-of-thumb methods; the engineer must be prepared to apply the accumulation of scientific knowledge to the more accurate solution of the problems with which he has to deal.

Believing that engineers and industrial leaders do not always recognize sufficiently the fundamental scientific principles involved in their work, it seemed advisable, in arranging the program for the Philadelphia meeting of Section M of the American Association for the Advancement of Science, that an effort be made to present the contributions that have been made by the fundamental sciences to the advancement of engineering and of industry; and, at the same time, to demonstrate that frequently the needs of engineers and of the industries have stimulated research in the fundamental sciences that affect them. The major portion of the program of the section was, therefore, in the form of a symposium at which each member of a group of distinguished scientists discussed the manner in which his particular science had influenced the work of the engineer and the development of industry. The importance of these discussions justifies their publication here, in the expectation that they will have a material influence in creating a better appreciation of the importance of scientific research.

[1] Papers presented in a symposium before Section M—Engineering—of the American Association for the Advancement of Science, Philadelphia, December 29, 1926.

ASTRONOMY

By Dr. FRANK SCHLESINGER
YALE UNIVERSITY OBSERVATORY

IN planning this symposium our chairman has arranged in alphabetical order the nine sciences that we are to hear from, and so astronomy has the first word. This science has had the first word in a more important sense, for it not only shares with mathematics the distinction of being the earliest to be cultivated, but it stands alone as the first to be applied to the affairs of mankind; without its aid our ancestors of thousands of years ago would have found themselves at a severe disadvantage in their struggle with nature and with rival nations.

Astronomy touches our modern lives so rarely that few of us have anything more than the merest acquaintance with the skies. But centuries ago, before there were cities, *every* man knew the stars and their habits intimately. This knowledge had much to do with the esthetic and religious development of early man, but of this we are not to speak this morning, as we are for the moment concerned only with the relation of astronomy to industry. All early races have used celestial objects as timepieces centuries before any artificial device for the same purpose was invented. A mere inspection of the position of the sun by day and of the moon and stars at night can with practice tell us the time within a few minutes. These objects were also made to serve as calendars to tell how much of the year had elapsed and particularly to indicate when various crops were to be planted. This was done by noting the times of heliacal risings of certain bright stars. The sun in his apparent annual journey among the stars renders invisible by his brilliance for several months those that are for the time in the same general direction. The first morning that a bright star can be distinguished in the glare of the rising sun is the date of that star's heliacal rising, and to a faithful watcher it tells how much of the year has elapsed with an uncertainty of only a day or two. From these happenings, or from the corresponding heliacal settings in the rays of the western sun, were fixed the days of sowing, the best times for this having been determined through sometimes centuries of accumulated experience of a particular nation in a particular locality. This knowledge was transmitted by word of mouth from father to son for many generations, and constituted a priceless asset for the nation or the race.

To those who live by the sea and to those who merely live near the sea, the rhythm of the tides is still one of the most important things in nature. All primitive races must have noticed very early the intimate relation between the times of high tide and the position of the moon; and soon thereafter the connection between the fullness of the moon and the fullness of the tides must also have forced itself upon their attention; in other words, they could not have failed to notice that at new moon and again at full moon, the high tide is higher and the low tide is lower than during the intermediate intervals. These are important facts to those who must launch and beach even the smallest of ships, and this business is much facilitated if we can predict, as we can, the time and the nature of the tides from an inspection of the moon.

To such an audience as this I need hardly dwell at length upon the contribution that astronomy has made to commerce by providing the mariner with the means for telling where his ship is.

Without this help navigation would be confined to the dangerous and time-robbing necessity of groping along coasts. Without it important portions of the earth and their products would doubtless still have remained unknown to civilized man, and the whole fabric of the world's industrial organization would have been very different from what it actually is.

It is a curious fact that the progress of science has taken away from astronomy almost all its ancient opportunities to serve the industries. We no longer use directly the sun and stars as timepieces and calendars; and we no longer need to observe the moon to foretell the tides; all this information comes to us in the convenient form of printed almanacs. Even as a help to navigation, astronomy is no longer as indispensable as it once was, and it is, I think, soon to lose its place altogether as part of the mariner's equipment. The problem of navigating may be divided into three parts: the determination of the time at some standard port (usually Greenwich, in England); the determination of the local time; and the measurement of the latitude. Of these the first has until recently been the most difficult, but the broadcasting by radio on every sea of accurate time signals has made Greenwich time very easy of access and very certain. The perfection of the radio direction-finder, which even now is in a sufficiently well-advanced state to warrant its use, will probably in a few years render it unnecessary for ships to make use of any kind of astronomical observations or calculations.

But if the passage of time has deprived the astronomer of some or most of his ancient opportunities it has also provided new ways in which he can be of service to industry and engineering. You will not expect that these contributions will vie in number or importance with those that other sciences have offered, for astronomy is now farther removed from the affairs of men than any other science. We may distinguish between pure and applied chemistry, between pure and applied physics, between pure and applied geology and so on through the list. But we can not make a similar distinction in astronomy: it is all pure. Whatever contributions astronomy has made of the kind we are discussing have, as Wells expresses it, been thrown over the shoulder of an investigator who is intent upon a very different task. In the short time at my disposal this morning I shall not attempt to enumerate these contributions, even though the list would be a short one as compared with what might be compiled in other fields. Let me instead dwell for a moment upon a single instructive example, namely, that presented by spectrum analysis. Peculiarities in the light of burning elements were noted as early as 1753; during the century that followed, the foundations of the subject were vaguely sensed by many experimenters, but it was not until 1859 that the physicist Kirchhoff and the chemist Bunsen, working together, formulated the laws of spectrum analysis and put the subject on what we might call a production basis. In doing this they had recourse not merely to results in their own laboratories, but also of another in which the conditions were fortunately very different, namely, in the sun, and their deductions followed a comparison of solar and terrestrial spectra. It was thus from a happy combination of the findings of the astronomer, the physicist and the chemist that science and industry were put into possession of this new and powerful weapon. This partnership in spectrum analysis has persisted ever since; it has yielded, and doubtless will yield in the future, knowledge of the most valuable kind in every sense. A single example must suffice. In 1868 Lockyer, observing the spectrum of the sun's atmosphere, noticed a set of

bright lines which could not be identified in the spectrum of any known terrestrial source. He inferred that they must arise from an unknown element which he named helium. Nearly thirty years later this element was "run to earth" by the chemist Ramsay, who found Lockyer's lines in a Scandinavian mineral called clevite. Lately pure science has handed helium over to the engineer who, among other uses for it, fills dirigible airships with it and who has learned how to produce it in large quantities.

These few examples illustrate a truth concerning which I am sure you will hear again to-day. If we were to confine ourselves to those contributions that come directly to industry and engineering from a particular science, we should miss the best part of the story. Just as great advances are very rarely the product of a single mind, almost as rarely are they born and nourished within the confines of a single science. It is for this reason as well as others that the organization and coordination of scientific effort is of the highest importance, not only from the point of view of pure science but even more so from that of the industries. And pursuing this thought a step further, let us ask ourselves how long we should continue to keep up our rapid advances in industrial progress if for any reason the march of pure science were retarded. It was long ago wisely said that to bring up a youth properly you must start by training his grandmother.

BIOLOGICAL SCIENCE

By Professor HENRY B. WARD

UNIVERSITY OF ILLINOIS

In the childhood of the human race by man's contact with living things on which he depended for food and from which he manufactured clothing, tools and weapons, this primitive study of biology gave the impulse for the construction of traps, pens, pitfalls for capturing his prey and for primitive industries by which the materials obtained were more fully utilized. This fundamental relation of biology to industry has been maintained ever since. Terms such as horse power, work energy, fatigue, etc., owe their origin and their carrying power to biology. Wood and its products, a variety of fibers, leathers, bone, glue, oils, fats, creosote, rubber, charcoal, bone and a multitude of other materials, some long in use and others newly found, are the basis for countless industries and are essential factors in the work of the engineer. Biological studies on the structure, origin and physiological characteristics of such materials furnish a firm foundation for their utilization in industry and engineering.

The microscope is probably the most important instrument which industry and engineering owes to biology. From the simple lenses used by fourteenth century students of biology to the complex and powerful compound microscopes of the present the improvements have been developed in the effort to penetrate further into the intimate structure of living organisms and to approach nearer the solution of the problem of life.

The discoveries which enable man to control fermentation and to use sterilization enter into the processes of modern industry in an essential manner. These processes worked out

in biological research though more striking than others, represent a long series which have been contributed by biology to engineering. Even the data for the effective handling of flood prevention came from biological studies on root systems of plants and their relation to soil as well as on the types and habits of burrowing animals. In the solution of a great present-day problem, the protection of harbor construction against the shipworm (Teredo), the biologist and engineer work side by side. When the existence of the silk industry was threatened with destruction, the studies of the biologist furnished both the explanation and the remedy. Centuries of study of the flight of birds eliminated misconceptions and determined fundamental factors in form, plan of operation, relation to air-currents and other essential elements utilized in aeronautics and aviation.

Sanitary engineering is of all most deeply indebted to biology. The contributions to it in our own country of W. T. Sedgwick, the biologist, and of a host of others, have made possible modern processes of water purification and sewage disposal. Utilized on a larger scale by the engineer these developments of pure biological research are of inestimable value to the human race.

Preventive medicine, which is a product of biological studies, affords essential aid to industry and engineering. Hookworm disease in mines, brickyards and agriculture, malaria, yellow fever, plague and similar diseases no longer paralyze commerce or cripple industry. Their control worked out by biology makes it possible to maintain public health and build great engineering works in regions where a century back disease was rampant and the very existence of the community difficult to maintain.

CHEMISTRY

By Dr. CHAS. H. HERTY
ADVISER, THE CHEMICAL FOUNDATION, INC.

WHEN some future student of our times evaluates the many services rendered the nation by Secretary Hoover I am confident that emphasis will be placed upon his appeal, as chairman of a committee of eminent men, for generous support from the industries for the prosecution of research in pure science. That was no idealistic appeal, but the direct outgrowth of a deep conviction that only through advances in pure science can industry hope to move forward at a continuously progressive rate. It is indeed striking that such a plea should come from the head of the great business department of our government. Whether the appeal proves completely successful is of incidental importance; one purpose is already accomplished—he has driven the thought home convincingly. That conviction can not fail to bring adequate response through one channel or another, unless, in the absorption of the everyday matters of our lives, we forget.

I take it that the function of this symposium is to assemble from all the branches of science a wealth of illustrations which may serve to keep the thought dynamic, that eventually it may be brought to abundant fruition.

Fortunately for my own responsibility here, the case of chemistry needs, perhaps, least elucidation. Within recent years there has developed among the chemists a group of popular writers—

Duncan, Slosson, Hendrick, Howe, Cushman, Free, Stieglitz, Hale, Harrow, Wendt and many others—who have given their time and talent to the presentation in attractive form of the story of chemistry in its relation to the manifold activities of life. Filled with appreciative knowledge of the dependence of industry upon pure science, this dominant thought is apparent throughout their writings.

Nor have we had to rely upon the random buying of books or the occasional glancing at publishers' announcements for the dissemination of such material. With the cooperation of many distinguished chemists, in the universities and in the industries, the Chemical Foundation has, by gift and by sale at actual publication costs, continuously developed an ever-widening circle of readers. No one can estimate the pervasive influence of the prize essay contest, founded as a memorial to their daughter, Patricia, by Mr. and Mrs. Francis P. Garvan, and conducted annually by the American Chemical Society in the secondary schools, public and private, throughout the nation.

Why, then, should I endeavor to augment what already has been so well done? One reason only—the full realization of how unevenly the processes of dissemination proceed and how necessary it is to repeat over and over again if we hope eventually to reach all.

But with the necessarily limited time at my disposal to-day, certain pertinent chapters must be chosen as illustrative of the prolific contributions of the science of chemistry to industry.

Much of our chemical industry was originally developed through pure empiricism, but the applications of new principles derived from pure science have revolutionized these industries and carried them forward with infinitely greater strides. Meanwhile, these same concepts have brought into being new industries which have enriched the world.

What branch of chemical industry is not indebted to John Dalton for his atomic hypothesis and to Avogadro for his supplementary conception of the molecule? What peace of mind could any manufacturer have if Lavoisier had not heralded the quantitative period in chemistry? Visit Niagara Falls and see the great electrochemical industries—then think of Michael Faraday and his fundamental concept. Watch the car loads of corn going into the great fermentation plants in the middle west or the tank steamers at Baltimore arriving with molasses, the waste product of Cuba's great sugar crop, then read the "Life of Pasteur."

In 1856 Perkin, seeking to prepare quinine from aniline, accidentally brought into existence mauve, the first aniline dye. It is not difficult to believe that had we been dependent on such casual methods alone progress in the field of coal-tar compounds would have been halting and uncertain. Kekulé in 1865, with his vision of the structure of the molecule of benzene, C_6H_6, changed the situation completely. The evidence marshalled to support his belief that in this molecule the six carbon atoms are linked to each other to form a closed chain made clear many facts which could not theretofore be explained. Of far greater importance, this concept of pure science presaged the discovery of many new compounds. Order was brought into the whole system of coal-tar compounds, and research on the production of thousands of these derivatives was feverishly stimulated. Upon the basis of this fundamental theory have grown our great coal-tar industries—synthetic dyes, medicinals, aromatics, flavors, photographic chemicals, high explosives and many war gases.

At the eighth international congress of applied chemistry, held in New York

City in 1912, Professor Bernsthen, of the Badische Anilin und Soda Fabrik, gave a lecture, with demonstrations, on the synthesis of ammonia from hydrogen and atmospheric nitrogen by passing the mixed gases over a catalyzer at increased temperature and pressure. He announced the laying of the foundations of the first plant for the manufacture of synthetic ammonia. This was the industrial application of the brilliant research in pure science by Professor Haber. As a climax to his demonstration, Professor Bernsthen held a piece of white cloth before the exit tube of the apparatus, and as the ammonia fumes touched the fabric it was rapidly transformed into an American flag which the professor enthusiastically waved before the audience. Little was it realized, as we applauded the striking phenomenon, that within a few years, as a result of this successful utilization of pure and applied science in Germany, thousands of American lives would be sacrificed as they followed that flag on the battlefields in France.

Not many years ago the producers of cottonseed oil in our southern states spent much time and money on fruitless efforts to persuade the housewives to substitute this liquid fat for lard, the semi-solid fat of the hog. Meanwhile, in the quiet laboratories of a French university, Sabatier and his co-workers were deeply engrossed in a pure science study of the transformation of unsaturated to saturated organic compounds. Sabatier showed that the addition of the necessary hydrogen atoms could be readily effected by the use of finely divided nickel as a catalyst. Cottonseed oil is a mixture of glycerides of unsaturated fatty acids. On hydrogenation by Sabatier's method there resulted saturated compounds which were solid. Then by careful regulation of the hydrogenation process a semi-solid fat, a true synthetic lard, was produced. The prejudices of the cook thus overcome, a great new industry was created, and again pure science had made industry its debtor.

While organic chemists were absorbed in developing the many new lines of work suggested by Kekulé's views, there appeared in the Transactions of the Connecticut Academy of Sciences, in 1876, a contribution so cloaked in mathematics that chemists did not realize that Willard Gibbs' phase rule was an epochal addition to chemistry. When years later it became understood, its application brought clarity and scientific basis to many processes which previously had been purely empirical. Industrial applications were rapidly made. The whole field of alloys, particularly that great tonnage alloy, iron and carbon, took on a new light; the problems of Portland cement became clarified; and in a multitude of other lines this fundamental research proved of inestimable value.

Sometimes, however, the worker in pure science is discouraged by seemingly unfortunate properties of the material with which he works. So in 1872 Baeyer found that phenol and formaldehyde formed a condensation product, but it was not crystalline. He saw no attraction in study of the gummy, resinous mass. Baekeland, however, boldly attacked this problem, and created the new synthetic resins, the uses of which seem to be unlimited.

The beautiful finish on our automobile bodies to-day is an illustration of the complete revolutionizing within the last few years of an old, established industry, that of lacquers, made possible by the work of Whitaker and his research staff in the U. S. Industrial Chemical Company. All accepted methods for making ethereal salts, such as ethyl acetate, involved high concentration and a dehydrating agent. This meant high cost, for the available acetic acid varied below 15 per cent. concentration. Whit-

aker resolved to put his whole staff on a pure science study of the question of esterification. Rates of reaction between alcohol and acid, equilibrium conditions, concentration of catalyzers, and similar problems were thoroughly studied. To quote his own words: "Months were required to complete these investigations, but the facts once established presented an entirely new view of the problem, saved months of time spent on mistakes, or perhaps avoided final failure." The net result of the work was the installation of a continuous process for esterification of dilute acetic acid, from which there is produced a monthly output of 150,000 gallons of chemically pure anhydrous ethyl acetate.

In the preceding illustrations, mention has repeatedly been made of the use of a catalyst, a substance which affects markedly the rate at which chemical reactions proceed, without itself being affected by the reaction. Here the purest of pure scientists have been gross empiricists. Catalysts have been used for many years, but the selection of the proper catalyst has been the result of haphazard discovery or the application of the "cut and try" method. Yet we are dealing with one of the fundamental principles of chemical reactions, and, from the standpoint of industry, with one of the greatest dividend-paying agencies. Shall we rest content with empiricism? Do we not know, from all other experience in matters chemical, that when once we understand the scientific explanation of catalysis we may look forward with confidence to the opening of entirely new chapters in chemistry and its application?

Fortunately Langmuir has brought some light into this all too clouded field. To-day Princeton University, through the work of Hugh Stott Taylor, has become the center for the scientific attack on this problem. It is a sad commentary that, in this period of construction of magnificent chemical laboratories in our universities throughout the country, Taylor's work must be carried out in the old and dingy basement of a laboratory utterly inadequate and ill-suited to the needs of a great university.

This thought brings me to a fundamental question: "How should research in pure science be supported?" Are most favorable conditions for its successful prosecution to be found in our universities, in the research laboratories of our more progressive corporations, or in endowed institutions?

The resources of the universities, whether derived from taxation or endowment, are frequently too limited to provide adequate equipment and sufficient associates to ensure the maximum output of men of fine talent, and too often their research is spasmodic, interrupted by teaching duties and administrative responsibilities. Yet research work under the influence of a noble teacher, and within the walls of a great university, is inspiring. From this source, too, must come the supply of well-trained research workers.

The seductive allurements of the larger salaries offered in industrial work have so depleted our university staffs that industry is at last awakening to the short-sightedness of this policy. That is the solid foundation on which rests the appeal of Mr. Hoover's committee. The successful culmination of their plan for support by the industries of university research in pure science, to the extent of $2,000,000 annually for ten years, would restore the equilibrium.

One can not but rejoice in the awakening of the petroleum industry, as evidenced by recent contributions to aid fundamental research in the pure science hinterland of that industry. Under the direction of the American Petroleum Institute, problems suggested by a group of scientists are being assigned to those workers in university laboratories whose

experience and equipment seem best to meet the needs of a particular study.

From the research staffs of industrial laboratories contributions to pure science will continue to be received. It is a wise investment for a corporation thus to make sure that it will be the first to realize upon the practical application of a new development in pure science. Yet research in pure science will always necessarily be of secondary importance in an industrial organization.

From privately endowed research institutions we have a right to expect real contributions to pure science. Their staffs are not under the seeming necessity of frequent, and therefore often premature, publication as offering the best means for preferment; nor are they under the pressure of making an immediate showing to directors more interested in the treasurer's balance sheet than in the report of the director of the research laboratory.

Excellent as have been the results from all these existing agencies, the fact must be faced that in none of them is the matter of research in the pure sciences the primary purpose and goal of the organization.

I remember well my last talk with the late beloved Dr. Wallace Buttrick, of the General Education Board. He had been besought to recommend financial aid to an undertaking in a rather restricted field of scientific research. He told me that he couldn't get up any enthusiasm for the proposal, that more and more he was coming to the conviction that funds should be found for creating a great institution where our ablest scientists could carry on fundamental research in all branches of science under conditions as nearly ideal as could be furnished. That was the ripened judgment of a man who had given the many busy days of a long life to aiding every form of education and research. His thoughts were always progressive; his feet always upon the ground.

If Dr. Buttrick was right, and I hold that he was, where should support for such an undertaking be sought? Granting as axiomatic that progress in applied science is strictly delimited by the advances in pure science, who would profit most? The answer is—each and every one of us. Not the manufacturer, except incidentally. Witness the constantly lowered cost to the consumer of electric lighting, of automobiles, telephones, aluminum and a host of other commodities.

If, then, we the public are the chief beneficiaries of the advances in pure science, it behooves us as thrifty citizens to busy ourselves with the problem of providing those ideal conditions which will ensure the maximum output which the human brain is capable of producing.

How can such collective action be taken? By federal taxation and Congressional appropriation of funds adequate for the creation and maintenance of a national undertaking where ideal conditions for research in pure science, both as to personnel and equipment, will be afforded.

I know full well the many objections to such a proposal which arise at once in your minds. Of course the next Congress would not appropriate funds for this purpose. Naturally politics would make itself felt in such an institution. Governmental red tape would certainly be restrictive on originality. These, however, are conditions of to-day. I am not of those who scoff at Congress. Our representatives in Washington, I believe, endeavor to carry out faithfully that which they are confident is for the best interest of the whole nation. They fairly represent the average thought of our people.

My proposal is based upon the as-

sumption that the men of science will during the next few years carry on an even more intensive campaign of popular education which will result in each citizen seeing clearly how much he has at stake in this matter. Confidence in the reasonably early success of such an educational undertaking is begotten of an intimate knowledge of the ways by which our people have so quickly grasped the facts of the close relation chemistry bears to their everyday lives. That was no miraculous revelation, but the result of the thoughtful, earnest, self-sacrificing work of many men who deemed it primarily a duty to their country—and they have gotten a lot of fun and happiness out of doing it.

With a nation thus aroused as to the determinative influence pure science has on human advance, Congress could not fail to heed the popular demand that an adequate part of the country's taxes be appropriated for this worthy purpose.

ECONOMICS

By Professor JOSEPH H. WILLITS
UNIVERSITY OF PENNSYLVANIA

In 1886, Henry R. Towne presented his address on "The Engineer as an Economist" before the American Society of Mechanical Engineers. In this address he may be said to have first given the fact that engineers and others who became industrial managers deal not only with problems of materials, machines and power, whose roots lie in such fields as chemistry, physics and mathematics, but also with such problems as cost, value, price, markets and labor, whose roots lie in whole or in part in the field of economics. That thesis has been so frequently repeated from innumerable pulpits, in the literature of the field of industrial management and by the increase in student enrolment in courses that include work in theoretical and applied economics and in a thousand other ways that its repetition here amounts to an unnecessary dwelling upon the obvious. To state the contribution adequately would require a book of many pages; one must needs in the space allotted for this paper limit the discussion to general statements with only a few illustrations.

One hesitates to use the method of analogy in view of the pitfalls of that method. With the hope that my audience, however, will recognize that no man's analogy should be followed to all its logical conclusions, I will resort to such a method in stating the general contribution of economics.

The development of ocean transportation has contributed much to the world in extending the area of our commercial interdependence, in extending the range of our intellectual interests and in promoting understanding and unity among peoples and nations. In making possible this development of ocean transportation we may distinguish three chief sources of contribution as follows:

(1) All the work of the scientists and the craftsmen whose labors have contributed directly or indirectly to the development of the technique of shipbuilding so that from the dugout of the savage there has evolved the modern *Leviathan*.

(2) All those practical seamen—those operators of ships—whose practical problems and experiences have been written down either in the log-books of

their ships or the mental log-books of their craft. Their contribution has been a contribution of practical seamanship.

(3) But ocean transportation would not have fared well and would still remain a precarious venture had we developed nothing beyond marvelous ships and fine old "sea-dogs" as captains. Our confident steering on a fixed schedule over all the oceans of the world could never have come about without a third contribution—the contributions made by that long series of scientists—which led to the development of the laws of navigation. The scientific studies which made possible the development of the technique of shipbuilding and the laws of navigation reduced the emphasis on empirical seamanship and lessened our dependence upon those romantic and daring figures "who braved the unknown seas." In the words of Kipling:

> Our dial marks full steam ahead,
> Our speed is timed to half a turn.
> Sure as the tidal trains we ply
> Twixt port and port. Romance, good-bye!

But in place of romantic, heroic, empirical seamanship, we have a science (and an art) of navigation.

The world is similarly engaged in the evolution of a science (and an art) of industrial (or business) management. The contribution of economics—theoretical and applied—is a contribution towards the development of laws of navigation in the industrial ocean. Developments in the industrial field are not analogous to developments in the field of ocean transportation in at least one respect. In ocean transportation, the laws of navigation were evolved in advance of any considerable development of the technique of shipbuilding. When therefore the developing needs of the world called for much transportation of goods and people by sea and when large ships had been developed for such service, the world already knew how to navigate such boats.

But another condition obtains in the industrial world. As a result of the applications of scientific discoveries our whole industrial machine has grown almost overnight to proportions that dwarf the most complex *Leviathan*—entirely too rapidly, for there to have been any corresponding development of laws of navigation in the industrial world. In industry, our knowledge of "where to steer" has not kept pace with our knowledge of "how to build the machine." In industrial management, we are still midway between the stage of high-grade empirical seamanship and a science of navigation. To put it another way, we know how to manage machinery and we know how to use materials, but we are still in the elementary stage of learning many of the fundamentals to effective administrative steering which are involved in the managing of men, of finances, of markets and of production. Just as the contribution of the physical sciences was essential to the development of the industrial machine and of our understanding and use of materials, so is the contribution of economics and the various related social sciences fundamental if our colossal industrial machine is to be effectively administered and wisely controlled in the interest of all. In the words of the late Alfred Marshall, "The need for such guidance in the practical conduct of life was never as urgent as now."

The experience and records of individual business enterprises and individual managers of industry constitute the log-book of each enterprise. This log-book is concerned with the individual experiences, problems and deviations from course of that enterprise. The economist is concerned with the principles which determine the general course

in contrast with the details which determine individual fluctuation. The economist is interested in the long run and from the facts derived from a multitude of industrial log-books and other sources seeks the general cause or tendency. He is also concerned in the social or national effect of such general tendencies. To quote Alfred Marshall again, "Economics aims to gain knowledge for its own sake and to obtain guidance in the practical conduct of life, and especially social life." And further, "It aims . . . at helping to determine not only what the end should be but also what are the best methods of a broad policy devoted to that end." "But though thus largely directed by practical needs . . . it shuns many . . . issues which the practical man can not ignore; and it is, therefore, a science, pure and applied, rather than a science and an art."

But these philosophical comments upon the nature of the contribution of economics leave one with only a vague conception of that contribution. One may distinguish four major forms of contribution, as follows:

I. "The Definition and Scientific Study of Phenomena and Problems in Economic and Business Life."
II. "The Training of Research Workers for Industry."

Of a less direct character but of equal importance, we may distinguish the following:

III. "Education for Administration in Industry (and Business)."
IV. "The Education of Public Opinion and The Elevation of the Standard of Business Ethics."

I. The Definition and Scientific Study of Phenomena and Problems in Economics and Business Life

There is not an aspect of the big fields of economics or of industrial life to which an important contribution has not been made by students of economics. I will cite but one example of that contribution—the contribution to an understanding of the so-called "business cycle." Industry has always been a prey to recurring cycles of business depression. Until the economists undertook careful scientific analysis, the business cycle was regarded as a single phenomena occasioned by many curious causes of which sunspots may be taken as an illustration. The analysis of crises, beginning a hundred years ago and continuing with increasing thoroughness as scientific methods and quantitative data were developed, has revealed that there is not one business cycle but many business cycles, one for each industry or trade and even for each individual business. It has been revealed that each cycle may be broken down into its four periods—revival, prosperity, crisis and depression; that each period has its own definite characteristics of economic activity, of prices, of money rates, of credit conditions, of labor disturbances and related matters. When to the results of these analyses there was added the possibility of reliable statistical measurement of the cyclical movement, the way was open for a complete breaking down of the cycle into its constituent trends and details. With these developments, the possibility of industrial adjustment to that multitude of trends and conditions which is roughly described as the business cycle became possible. There could be no problem of business forecasting so long as all the factors were considered as one unit. But given the scientific analysis which I have briefly described, the world bloomed with efforts by individual companies, by whole trades, by financial institutions, by government bureaus and by business services to forecast business activity or a particular corner of business activity and adjust policies accordingly. These efforts were and are crude. The path

was, is and inevitably will be strewn with the tragedies of damaged reputations. But evidence is conclusive that we have made progress towards control of the fluctuations in business activity. The imagination is challenged by the possible future contributions to general business stability, to enlightened industrial management and to the release of the human race from the fear of unemployment.

What many economists under the leadership of Professors Wesley C. Mitchell, Charles J. Bullock and Warren Person have accomplished in the fundamental analysis of the business cycle might be duplicated in almost any field. The work of Commons, Pigou, Hoxie and Bezanson in the field of industrial relations; of Johnson in the field of railroad transportation; of Tryon in the field of the economics of power; of Seligman and Kemmerer in public finance; of Marshall and Taussig in economic theory; of the National Bureau of Economic Research in income; of Huebner in insurance and of all economists in defining the concept of production as distinguished from that of mere trading—all are only illustrations of the service performed by economics in analyzing those fundamental phenomena which are too complex and obscure for the individual industrial manager to assay alone, but with which his daily decisions must be in adjustment if he is to manage wisely.

II. The Training of Research Workers for Industry

This contribution is always a major contribution of science to practical life. A census of the heads of departments in industry devoted to research in economic, financial, commercial and industrial problems would reveal an overwhelming percentage of men who had had graduate work or had taught in these fields at universities. Leonard Ayres, of the Cleveland Trust Company, Stewart, of the Federal Reserve Board, Berridge, of the Metropolitan Life Insurance Company, Parlin, of the Curtis Publishing Company, Lincoln, of Western Electric, and B. M. Anderson, of the Chase National Bank, are only a few of the more familiar examples.

III. Education for Administration in Industry (and Business)

The expansion of industry during the last hundred years—even during the last fifty years—has been so tremendous as to amount to a revolution. Eighteen seventy-five was literally ancient history from the standpoint of modern business development. As David Houston has pointed out, greater changes have occurred in that period than occurred in the thousand years preceding. And one of the important results of these changes has been the demand for a larger amount and a higher quality of talent for industrial administration than the world had ever before needed. The direct educational response to this demand can not be included in the category of a pure science. But next to experience, economics contributed most fundamentally to this shifting of talent. It supplied the fundamental studies upon which education for business and industrial administration had to be based; it supplied that material in the form of textbooks so as to make education generally possible; and it supplied—inadequately, it is true—but nevertheless supplied, most of the demand for teachers in these new fields. This contribution could never have been made without the underlying scientific labors of all the deductive and inductive workers in the field of economics. Without them our business schools and our courses in industrial engineering could never have come into existence.

IV. The Education of Public Opinion and the Elevation of the Standards of Business Ethics

The theoretical and applied workers in economics were doing more than educate college boys who might some day become managers. With their scientific studies, their text-books and their teaching, they were educating an entire population to some measure of understanding of the problems and phenomena of the new world in which we had so suddenly found ourselves. Negligible though that understanding still is, it is extraordinary compared with that of a quarter century ago. To-day, therefore, the acts of industrial leaders are carried on before an audience increasingly interested and informed on industrial problems. One result of the greater public understanding and of the university education in management and administration has been to bring more and more of the professional spirit to industrial management. With the development of that professional spirit has come an elevation of ethical standards so that the business standards of the eighties would not be countenanced to-day.

With all these shifts in the problems confronting us and in the tools available with which to meet problems, it is not surprising that we are witnessing a shift in the type of business or industrial manager. In the epoch which we are leaving, the industrial leader was a man who did not consider risks too carefully, who used figures sparingly and played hunches. It was the type best fitted to survive, for we needed seamen, not navigators.

To-day our emphasis is shifting to the leader who is a careful planner, a skilful, thorough organizer who disregards hunches and assembles and studies the facts before making a decision. We are demanding industrial navigators who are familiar with the laws of industrial navigation.

GEOLOGY

By Professor HEINRICH RIES
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It is of interest to note that the science of geology which may be said to have originated not more than two centuries ago in the vague speculations of the cosmogonists, and which became well organized only within the last century, has within the last thirty or forty years been found to have such wide practical application that there has developed a well-marked and clearly recognized branch called economic or applied geology.

But although the practical applications of geology were not widely recognized at an early date, there is no doubt that its early development, even as a pure science, was partly in response to the miner's desire for accurate information regarding the occurrence and distribution of mineral deposits. Happily the benefits derived in this case were not all on one side, for the geologist in turn profited much by the information obtained from the sections of the rock formations exposed in mining and quarrying. Indeed, the detailed study of mineral deposits has sometimes aided greatly in the solution of many fundamental geologic problems.

Lyell in his classic work, "The Principles of Geology," has drawn attention to the fact that the contribution of different nations to geological science depended not alone on the genius of the

individual workers, but also to a large degree on the peculiar geologic environment of their fields of labor.

And so while we may say that because of these conditions mineralogy received a strong impetus in Germany, stratigraphy in England and paleontology in France, I think we may add that economic or applied geology has developed in the United States on a larger scale than in any other country, due to our important mineral resources and industries which cooperate closely with geology.

The increasing attention which applied geology has received from geologists has also been reflected in published writings, for, as pointed out by A. H. Brooks,[1] there were in 1890 less than 1 per cent. of the publications of the United States Geological Survey devoted to applied geology, while in 1910 98 per cent. of them treated of this phase of the science wholly or in part. The same has been true of other countries where geologic work has been carried on.

No better illustration of the importance of applied geology and its relation to industry can be given than to point out the well-recognized fact that mineral resources are an important factor in a country's development. The lure of gold and other metals has attracted thousands into new territory, while the search for oil has carried exploring parties into all parts of the world. When once the deposits of these useful materials are found and developed, railroads are built, towns may spring up and other industries take root. And so the development of industries based on mineral products and the carrying out of great engineering projects, whose completion has involved the solution of geologic problems, have not only stimulated the development of applied geology, but involved its close cooperations with engineering and industry.

We can therefore mention at least three ways in which this branch of geologic science makes itself useful. (1) Geologic knowledge is essential in the intelligent search for and valuation of mineral deposits; (2) the application of geologic principles to practical problems in engineering and other industries is often helpful; and (3) the geologist and mineralogist have by their investigations of the properties of the natural inorganic compounds found in the earth's crust accomplished much fundamental work, on which the chemist and physicist have built.

Some of the applications of economic geology deserve more than passing mention.

Water Supply

With the tremendous growth of some of our cities the engineer is sometimes forced to go long distances in order to obtain suitable and adequate supplies of water. Projects involving the construction of large storage reservoirs, dams and many miles of aqueduct tunnels or trenches to hold pipe lines are undertaken.

Here then he may be confronted by geologic problems from start to finish, several of which may be mentioned.

The selection of a reservoir site needs to be more than topographically correct, since it must also be watertight, and we have to consider such geologic features as the impermeability of the surrounding rock formations and the level of the water table around the proposed location. The question of silting up by the inflowing streams is a further matter which can not be neglected.

Similar geologic problems present themselves in the selection of a dam site.

No less important is the consideration of geologic features where an aqueduct is carried below ground in pressure tunnels, for its permanence and tightness

[1] *Jour. Wash. Acad. Sci.*, Vol. II, p. 19, 1912.

depend on the tightness and solidity of the material tunneled through. Permeable strata, water-bearing beds, crush zones due to folding and faulting and buried river channels are among the geologic phenomena which may cause no end of trouble for the engineer, unless he knows of their existence in advance.

The successful completion of one of the greatest engineering works in the United States, the Catskill aqueduct for New York City, which encountered all the above-named troubles, has emphasized the great advantage to be obtained by the proper coordination of geologic and engineering investigations. The experience gained here in the application of geology to engineering problems should serve as a splendid example to be copied many times in the future.

A second phase of water-supply work to be considered in this discussion is that of artesian supply, for not a few cities and rural communities are dependent on driven wells.

No water supply engineer, familiar with rock formation and structure and their relation to water supply, would assume that granite and sandstone were equally valuable as aquifers, or that because one region supplied an abundance of water to wells driven in glacial drift, it was possible to get a similar supply from another drift-covered area, even though the rainfall were the same at both localities. Geology has shown that certain rock structures and certain rock types are much more favorable as regards their water yielding capacity than others, so that a fairly reliable forecast can be made of what is to be expected in a given region, where the geologic conditions are known.

Railroad Construction

Here again geologic problems confront us. In driving tunnels through mountain ridges, we can not overlook the structure of the hill to be pierced nor material composing it.

The reports on the long tunnels driven through the Alps make most interesting reading, and emphasize clearly the benefits to be derived by cooperative work between the engineer and geologist. It is interesting to note that even in that region of highly folded strata the calculations and predictions of the geologist checked very closely with the facts as found by the engineer.

This however by no means ends the geologic problems that may arise in railroad construction, all of which may affect either cost or stability of road. These would include investigations of materials underlying depressions, danger from landslides, zones of faulting, relation of rivers to bridges, while in some regions, like Alaska, even glaciers can not be ignored, as by their advance or retreat they may directly or indirectly seriously threaten lines of rail communication. Perhaps equally important also is the investigation of new territory as to soils and mineral resources, which can yield business to the railroad.

Miscellaneous Applications

Other examples of the relation of geology to civil engineering work might be discussed did space permit, but all that can be done here is to call attention to the need of considering rock types and foundation characteristics in road construction or of the bearing of a knowledge of stream action and wave work on river and harbor improvement.

The cause and possible prevention of landslides is another fruitful subject for consideration, and the troubles which they gave in the construction of the Panama Canal and at other localities serve to emphasize the need of being on the lookout for similar troubles elsewhere.

No less important is the problem of land subsidence caused in most cases by mining operations, but, by its upward spread, giving rise to serious surface disturbance. Much attention has been

given to this matter in Europe, and more recently in the United States. Many data have been obtained on the relation, nature and structure of the rocks to the direction and speed of the movement.

Military Science

A somewhat new departure in applied geology which has rendered conspicuous service in various ways in military work was that developed during the late World War. The selection of camp sites and the location of trenches and dugouts were made with respect to geologic conditions when this was possible, while the location of the water table, as in northern France, had an important bearing on the obtaining of water supplies and the operations of mining and counter mining.

Mapping

The making of a map is regarded usually as a purely engineering task, and while it is so to a considerable extent, nevertheless it is well to remember that surface topography is always the result of geological processes, and a geologically trained engineer can interpret this knowledge from a topographic map. If therefore we have some understanding of the foundation of our map, it can not fail but to assist us in giving our topographic features a "more intelligent look." Comparatively minor features, which may seem of no importance if their cause is not understood, can be properly emphasized if the reason for their being is known, thus making the finished product of the surveyor more valuable.

In this field, however, the geologist has been greatly helped by the aviator, for the introduction of airplane surveying has not only given us an accurate means of mapping surface features for exploration and geologic work, but has also resulted in a saving of much time and money.

Metal Mining

The relation between the geologist and the ore miner has been most intimate since each one has helped the other.

The perplexing problems presented by broken and displaced ore bodies call for careful geologic work in their solution, since the all-important point to be settled is where the ore has gone. The study also of the origin of ore deposits has thrown much light on their mineral composition, shape and extent, which assist in the operations of exploration, valuation and mining. We should not overlook either the results obtained by a study of the peculiar phenomenon of secondary enrichment, which it has been found affects certain metals more than others and represents a process to which some of the important ore bodies owe their workable richness at the present day.

Coal

It has been said that coal mining was the first branch of industry to which geology made itself indispensable[2] in mapping coal fields, tracing the beds, working out the thickness, number and quality, and other features of importance. In many regions the structure of the coal measures is relatively simple, but in certain ones of more intricate structure, the importance of geologic work becomes noticeable.

The world's geologists have performed a useful service in estimating the reserve tonnage of the different ranks of coal in the several coal fields of the world, and in the United States the federal geologists have prepared a map showing the areas underlain by coals workable under present conditions of mining and of

[2] Watts, W. W., Brit. Assoc. Adv. Sci., Toronto, 1924, p. 91.

those areas under which the coal lies too deep to be workable at the present conditions.

Oil

This mineral resource stands next to coal as a source of energy, and forms the basis of an industry which has shown tremendous expansion, due to the fuel value of petroleum, the use of which can be said to have revolutionized some branches of engineering practice. In response therefore to an ever-increasing demand, there is going on a world-wide search for new sources of supply.

Since oil reservoirs do not outcrop, the geologist has a less easy problem than in his hunt for coal.

Geologic knowledge, keeping pace with industrial development, has pointed out so clearly what the most probable structures are that seem favorable for oil accumulation that the oil companies carry a staff of geologists, whose exploration work involves a direct application of geologic principles.

Agriculture

While our thoughts may naturally turn to civil and mining engineering when the practical relations of geology are mentioned, there are other lines of human activity with which it cooperates.

Agriculture is an industry which is closely related to geology, for the soils which support the crops and on which the latter depend for food are to be regarded as rock types. Indeed, in making soil surveys, the classification of soils is based largely on their origin and so geological knowledge comes to the aid of the soil surveyor. This is more particularly true in glaciated areas like the northern United States, where the surface materials are largely of glacial origin. Familiarity, therefore, with glacial deposits and their physiographic character and relationships are most useful in soil mapping. The application of the principles and processes of weathering may also help to a better understanding of the soil and the formation of soil colloids.

Chemical Industry

Chemistry and geology are mutually helpful. Various chemical industries consume large quantities of raw mineral products, but since these vary in their purity and composition, it is important for the chemist to be familiar with the irregularities of composition which the different types may show, because he is often called upon to pass judgment on new sources of supply. Here geology helps the chemist. On the other hand, the laws of physical chemistry which the chemist has worked out are of great assistance to the geologist in explaining many geologic processes.

Electrical Industry

In the study of mineralogy, much knowledge has been gained of the internal structure of crystals and their relationships, so that when the physicist began the study of crystal structure by means of the X-ray, he received from the mineralogist the results of much preliminary work that served as a basis for his further study. A very important advance due in part to the study of crystal structures has been the development of permalloy, whose use in submarine cables, as is well known, has greatly increased the speed of transmission of messages.

Political Geology

Many of the most important industries of a nation are based on mineral products, this being true during times of peace or war.

That nation, therefore, which possesses or controls the greatest variety and reserves of mineral wealth enjoys a position of major economic importance,

which becomes an asset of incalculable value in time of war.

This was emphasized during the recent world conflict, and indeed it has not been overlooked in the past when the different nations of the world have been expanding their possessions, since they have not been blind to the possible mineral wealth of the territory whose annexation they sought.

It brings to the fore a branch of geologic science which has been called political geology, and the careful planning to acquire lands whose mineral resources are essential to important industries has been aptly referred to as the strategy of minerals.

To take one simple and clear case, reference may again be made to petroleum, for as already stated a world-wide search is being made for new fields, and the reason is simply that it represents one of the most valuable mineral resources known. That nation, therefore, which controls the greatest reserves occupies an enviable economic position.

The United States is at the present time the greatest oil producer, but we may question whether it has any longer the largest reserves. We have used our oil more or less wastefully, we have placed no ban on free exportation and we have been generous in allowing the nations of other countries to come in and exploit our oil supplies. Unfortunately, the last is a privilege which is not permitted us in all other countries at the present time.

Although the United States is at present the dominating nation in production, its consumption is greater than its output, and it is not unlikely that in the future there will be important shifts in the centers of world production.

Leith[3] has remarked that the more immediate problems are: (1) Whether the discovery and winning of oil can be made to keep pace with the enormous acceleration in the demand, and (2) the adjustment and financial control of oil resources, the possession of which is becoming so increasingly important to national prosperity.

Going on down the list of mineral resources we find that certain countries are far from independent industrially, while others are partially so.

The United States hardly dominates the world situation in anything except copper, and even here is not so important as formerly. She has, however, an exportable surplus of a number of mineral products, but is dependent on foreign sources for cobalt, nickel, platinum, tin and to a major extent for, asbestos and potash.

Great Britain, to quote an additional case, controls extensive mineral wealth in her colonies, but within her own borders lacks many essential mineral products.

These two instances, and others, serve to emphasize the marked degree to which different nations are dependent on each other.

Conclusions

From what has gone before it should be clear that geology is of service to man in two general ways. The first of these is in exploring and evaluating the mineral resources on which industry and civilization are built, and the second is the application of geologic principles to various lines of human activity, such as engineering, agriculture, chemistry, etc.

Both of these are phases of economic or applied geology, but neither could be developed before geology as a pure science was more or less firmly established, and in this process it freely acknowledges its indebtedness to some of its older sister sciences such as chemistry, physics, botany and zoology.

It furthermore indicates the close relationship which must exist between the different sciences, a connection so close

[3] "Economic Aspects of Geology," p. 130.

that one can hardly consider them as sharply separated from each other. In a similar way they are all in their practical phases at least closely related to the different branches of industry, ready to serve them in every way possible.

MATHEMATICS

By Professor GILBERT AMES BLISS

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SOME time ago your chairman asked me to prepare for this meeting a few remarks on the contributions which the science of mathematics has made to the industries. The subject is one which has a great interest for me, and I will try to give to you the impressions of a so-called "pure mathematician" with regard to it. Let us understand at the beginning that I believe the term "pure mathematics" to be a misnomer. It is true that mathematicians sometimes have prided themselves on their devotion to theories far removed from the contaminations of any sort of uses in other fields. I can sympathize with them to some extent, because the uncertainties of the physical or other bases for applied mathematical theories, combined with the vagaries of inexperienced mathematical reasoners, do sometimes together make what seems to the pure mathematician an awful mess. If experiences of the past are to be credited, however, it is from these messes that truth may be expected finally to emerge, whiter and more brightly shining by contrast, and not infrequently clad in the raiment of pure mathematics. Much of the product of pure mathematical research of the past has already been put to use in some domain or other, and much more will in time find application. For this reason, as well as for others which may be equally defended, it is the duty of the pure mathematician to have results in his science at all times well ahead of the applications, and on a par with the products of other sciences which are still unused but which may be in demand at any time to meet unexpected industrial needs.

For the purposes of the present discussion two types of applications of mathematics may be distinguished. There are in the first place applications of the commonplace everyday sort, based upon elementary arithmetic or algebraic or geometric principles which every educated person is supposed to know or which he can "pick up," as they say, for himself without serious difficulty if he is sufficiently interested; and there is a second less elementary sort of application which can be devised or understood only by those who have studied farther into mathematics more seriously and thoughtfully. We shall see later that the calculus constitutes a rather definite intellectual and psychological barrier between these two types of applications.

Of the first type I shall not have much to say. You probably did not come here to hear about them, and I shall not detain you long in speaking of them. But their importance in our modern civilization is undeniable. We all recognize the slowly rising tide of dissatisfaction with non-metric systems of measurements, or at least we have experienced in our travels the inconvenience of business transactions in a country in whose monetary system the first two decimal points represent twentieths and two hundred fortieths of a unit instead of tenths and hundredths. The economic waste of bookkeeping in

pounds, shillings and pence must be large indeed. But what would become of our present economic structure if we had no Arabic but only Roman numerals with which to carry through our arithmetical operations? What would become of a highly organized and complicated manufacturing or merchandising establishment handling hundreds of thousands or millions of units per year, with a delicately adjusted system of cost computing and accounting without whose accuracy neither success nor failure could be accurately predicted or measured. The answer is easy. Nothing would become of such an economic structure or of such a business establishment, because without the operations of elementary mathematics, as we now understand and use them, none such could ever have been developed.

These remarks have a certain triteness. We all recognize the indispensable significance of arithmetic and other forms of elementary mathematics in our daily life. The aspect of the matter which really needs emphasis, however, is that there is no mathematical process, either elementary or advanced, which is not the product of mathematical research in some bygone age. We are in the habit of accepting the subject-matter of our elementary curricula as property whose acquirement puts us under no obligation and demands from us no expressions of gratitude. But the most casual examination of the history of mathematics reveals the mathematicians of the past struggling with arithmetical notations; struggling to introduce and interpret the decimal point and the symbol zero after the other digits had been invented; struggling to develop operations of addition, subtraction, multiplication and division suited to the mechanisms of their respective methods of writing; struggling to operate with fractions by reducing them all to a common numerator unity instead of to a common denominator as at present; struggling to find the ratio of the circumference to the diameter of a circle; searching, seeking, investigating for our benefit just as we must constantly continue to do in our own epoch for the benefit of future generations if we would maintain our respect for ourselves as participants in the forward development of the human race. I have said already that a large part of the product of the mathematical researches of past generations has already been put to practical uses. Some of this product was at the beginning the response to economic demand, but much of it was the work of investigators who were spurred to activity by pure love of science and the applause and appreciation of their fellows. Let us see to it, if possible, that our own civilization appreciates and supports adequately the pure scientist, for if we do not do so progress will presently cease and we shall be regarded by men of the future as a selfish, self-centered, materialistic race.

I have spoken briefly of the applications of elementary mathematics in everyday life. Much more could be said upon this subject if there were time to do so. But there is not, and we may well turn our attention therefore to applications which are of a less elementary sort.

I suppose there is no plaintive request which is made more frequently to mathematicians by persons who have completed the formal processes of their education and entered actively into careers or professions of some sort, than the request for an elementary, and especially a short, presentation of the principles of the calculus. There is in fact no very easy road to an understanding of the calculus, though I hope and believe that ways can be found and books can be written which will make its principles much clearer and more readily accessible than they are to-day. The

great advances in the science of mathematics have been the product not of individual workers alone but of periods and schools. The roots of modern mathematical analysis reach back to antiquity, but the period of greatest activity in the developments of the elements of the calculus was the seventeenth century, and the great spokesmen of that period were Newton and Leibniz. At that date the fundamental principles of the theory were none too clear, and misunderstandings gave rise to many derogatory comments and lively scientific discussions. It was remarked by one of Newton's contemporaries that his new theory was a remarkable and brilliant piece of work, but that it would very likely never be thoroughly understood and appreciated except by persons imbued with unusual scientific interest and intellectual curiosity, a line of talk which is astonishingly like the comments on the theory of relativity which we hear to-day.

Very soon, however, it became clear that the new science would have a far more extensive application than was at first anticipated. During the eighteenth century the Bernoulli brothers and Euler, in Switzerland, and Lagrange, in France, formulated in terms of calculus notions a new theory of mechanics, and another Frenchman, Laplace, made great strides in the application of the theory to the motions of celestial bodies. It is true perhaps that in those early days theory predominated and the accuracy of the fit with natural phenomena was none too well established. In the nineteenth century, however, great progress was made in the process of adapting theory to practice in celestial mechanics, and the work is still in continuation to-day. Modifications have been made, such as the relativity theory, which are varied and important, but the foundations still rest on the researches of the men whom I have mentioned and their contemporaries.

I have spoken somewhat hastily about the origin and development of mathematical analysis and I should like now to mention some of the products of this development which affect materially the prosperity of the human race to-day. If you are on a voyage and strike up an acquaintance with the navigating officer of a ship and accompany him to the bridge, he will tell you perhaps that mathematics plays a very small part in the practice of navigation. If you are mathematically inclined you will be surprised at the limited amount of mathematical knowledge and computation which are required for the determination of the position of a ship at sea. A few observations and some elementary computation with the help of tables is all that is necessary. But one should not be deceived. There are few domains of applied mathematics where the operations used in practice have been so tabulated and systematized as they have been in the practice of navigation. Behind the tables of the motions of celestial bodies used by the navigator lies the whole history of the development of the calculus and its applications to celestial mechanics. Without Newton, Lagrange, Laplace, Hill, Poincaré and many others, who developed the theory, and without the Delaunays and Newcombs, who fitted the mathematics of their predecessors to the heavens, the problems of the modern navigator would be unsolved and international commerce as we know it to-day would be impossible. It is well known of course that the art of navigation has mathematics in it, but I think that few persons of the general public realize the distinctly mathematical character of the celestial mechanics upon which the theory of navigation is based. It is perhaps the most fundamentally important and effective single application of mathematics which could be mentioned.

There is another assistant to the navigator which has mathematics in it,

namely, his map. It is well known to mathematicians that the surface of the earth can not be mapped upon a plane in such a way that angles will be preserved and distances on the map be everywhere proportional to corresponding distances on the earth's surface. A map of this kind, if it were possible, would be most desirable and satisfactory. Since it is not possible to make such a map we must be content to approximate to it as closely as possible, or to construct maps for special purposes portraying accurately a part only of the geometrical properties of figures on the surface of the earth in which we are interested. Thus we may ask for a map preserving areas to scale; the battery commander in the field needs a map which preserves angles and indicates distances with the least possible error for a limited portion of the earth's surface; the navigator uses a map which represents loxodromes, or curves of constant direction on the earth's surface, as straight lines. To determine the course of a ship along such a loxodrome one needs only to rule a line on the navigator's map from starting point to destination.

Maps of all these types, and many others, have been constructed. Archimedes knew a fundamental property of one of the area-preserving maps, and Lambert and Bonne constructed others in the latter half of the eighteenth century. The maps of Bonne were used by navigators on the Atlantic for many decades. Curiously enough, the map now used most extensively in navigation is one published by Mercator in 1569. He described accurately its property of representing loxodromes by straight lines, but gave no theoretical explanation. Lagrange in 1779 invented a map which preserved angles and represented meridians and parallels as circles on the plane.

All these are special cases and there are many others. For the general principles applicable in the theory of map-making the mathematician would turn, I think, to a memoir published in Latin by Gauss in 1827 and whose title translated would be "General investigations of curved surfaces." This is a famous old memoir, containing principles useful not only in map-making but in many other domains of applied mathematics. It was the precursor, for example, of the geometrical theories of Riemann, and of Ricci and Levi Civita, and of the relativity theory of to-day. But I have said enough about map-making. Without maps and the mathematical theories of surveying which go with them, the navigation of the present, and many of our modern engineering enterprises, would be impossible.

There is a type of activity of the average university professor of mathematics which I think is fairly described by the term mathematical settlement work. It consists of efforts to answer questions of more or less serious mathematical character proposed by members of the faculty outside of the mathematical department or by members of the community outside of the university. These questions usually have little mathematical interest, but they sometimes have a very considerable significance for the proposers.

Questions concerning amortization of payments are common. A neighbor of mine, now very near the top in a large manufacturing concern, told me gleefully that he made his first favorable impression upon his superiors by solving a mathematical problem of amortizing the costs of sprinkling systems for a flock of factories against savings in insurance premiums. It took him a "week of nights," to use his own words, to find and check by cut and try methods the results he thought he needed, but the net result was an annual saving to his company, after a period of years, of a good many thousands of dollars. Mathe-

matically the problem had no real difficulty, though, as I remember it, a method of approximation was necessary for its solution if tables were not used. I should hate to think that there are many such situations in the business world whose mathematical possibilities go unrecognized.

An efficiency expert called upon me unexpectedly late one Saturday afternoon. He seemed at the same time excited and depressed, and it turned out that he had been trying for several days to construct norm curves for the guidance of salesmen for a certain business house, in accordance with specifications prescribed by its chief executive. He was disturbed in his mind, talked rapidly, and it was impossible to think while he was present. But within a half hour of his departure it became clear, by a mathematical demonstration which was agreeable to me at least, that curves of the kind demanded were impossible. A number of different curves could be constructed, each having some of the properties specified, but there was no single curve possessing all of them. I naturally hastened to the telephone to bring relief of mind to a fellow mathematician in distress. But the effect was far from satisfactory, for what chance has mathematics in the mind of an efficiency expert as opposed to the instructions of a business executive?

From questions which reach us it seems that graphical methods or special tables, often expensive to prepare initially, might in the long run be economical in many situations in the business world. Some years ago one of our students graduated and went into business with his father in the manufacture of boxes. He found that their salesmen were having difficulty in computing costs. The costs depended upon seven variables corresponding to different sorts of materials which might be used. The computations were frequently long and embarrassing in the presence of a customer, and sometimes it was necessary to appeal to the home office. One of the members of our department devised a graphical method which relieved the situation. The cost of computing the tables and drawing the graphs was twelve hundred dollars, but the box manufacturer seemed satisfied, for the average computing time for his salesmen was reduced to two minutes.

Not very long ago a patent attorney came to me from a manufacturer of large storage tanks. He wanted advice in the design of tanks on which the pressure of the contained liquid should be at all depths the same, so that the tank could safely be constructed with a skin of uniform strength and thickness. With the connivance of a physicist the differential equation of the form curve for the side of the tank was set up, but it proved to be of a type which could not be solved in terms of elementary functions. A formula familiar to differential geometers, but beyond the curriculum of the average engineer, furnished an effective graphical method of solution. Designs for such tanks have now been made by engineers and are being patented. The problem is related to the well-known mathematical problem of the determination of the form of a drop and has considerable mathematical interest. If I had pursued the investigation to its finish I should have wanted to inquire carefully into questions of stability, but engineers have doubtless methods of their own for insuring safety in this respect.

I have mentioned these mathematical incidents, not because any one of them is of great importance in itself, but because, if they are as a group typical, they indicate that business and industry are permeated with problems which are not only susceptible of mathematical treatment but whose satisfactory solution requires such treatment. There are

many others which might be mentioned. It amused me the other day to hear from an economist that one of the great mail order houses has mathematical formulas regulating each day the speed of operation of various departments as functions of the weight of the morning mail sacks. There must be many mathematical situations whose mathematical character escapes notice, and not always perhaps on account of the inexperience of executives. I should like to relate to you an experience of my own which shows that sometimes a really intimate acquaintance with a problem may be necessary before its nature can be well appreciated.

In 1918 one of my mathematical friends, Professor Oswald Veblen, of Princeton, was taking a prominent part in the ballistical work at Aberdeen Proving Ground. He wrote urging me to join the group of mathematicians associated with him there, but I refused, because my experience in ballistics was that of the merest dilettante and because I thought I could be of greater service elsewhere. His insistence was so urgent, however, and my confidence in his judgment so great that I finally agreed to his proposal. My surprise, upon becoming acquainted with the problems of his staff, was complete. Before the war the theory of ballistics contained an approximation, valid only for trajectories with low initial elevations, whose application made it possible to integrate the differential equations of a projectile in terms of elementary functions. The theory was satisfactory until long-range guns began to be elevated above twenty degrees, and then it became necessary to revise it completely. The new methods, based on principles altogether different from the old ones, were provided by mathematicians and are ably presented by F. R. Moulton in a recent book on exterior ballistics containing much new and remarkable material which he himself and others have contributed.

The particular problem in which I was with others interested was the computation of differential corrections to the ranges of projectiles due to such causes as variations from normal in the temperature or weight of the powder charge, variations from normal in the weight of the projectile, winds, and variations from normal in the density of the air at various altitudes attained by the projectile, and for very long trajectories the rotation of the earth. The computation and tabulation of these corrections in form convenient for rapid use by the battery commander in the field is a complicated mathematical problem, and is a fundamental problem of range table construction. It is also a very costly and arduous one on account of the large variety of projectiles whose behavior must be studied and tabulated.

When the initial velocity and elevation of a projectile is given the range under normal conditions is theoretically uniquely determined. But if a wind is blowing it may vary widely from the computed value, and the projectile may fail to reach its mark. The velocity w of the wind at various heights is determined as a function of the altitude y by sending up a small balloon and observing its positions at equal intervals of time, and the range of the projectile is a function of the wind-function $w(y)$. I do not wish to enter here into mathematical details farther than is necessary to indicate that the range as a function of the winds is a function of a new type. It is not a function of a single variable, or of several variables, such as one commonly meets in applications of mathematics, but it is a function of another function or, as mathematicians sometimes call it, a function of a line. The computation of the first differential of this function is the computation of the wind correction to the range.

Now the theory of functions of lines is on the farther boundary of the explored mathematical domain of to-day,

and I for one should never have expected it to have an application in ballistics. Its methods were effective, however, for they reduced by three fourths the labor in computing the most numerous corrections in the range tables, and the cost of these improvements in terms of scientific experts was negligible in comparison with savings which would presently have accrued if the war had continued. I may add that the importance of accurate range tables can hardly be over-estimated. An improvement in a range table which might reduce by one the number of shots fired for adjustment from a fourteen-inch gun in order to attain a target, would on each such occasion save one third or more of the average salary of a scientific expert at 1918 rates. I leave you to make further computations if you are interested.

It seems to me that this bit of applied mathematics is interesting in itself and that it illustrates principles upon which I have insisted here before. No one can foresee what portions of the science of mathematics of to-day may have applications in the future.

I have said very little up to the present about the theory of statistics and its ever-widening field of applications in business and industry. Of the mathematics of the actuary I shall have little to say. From the standpoint of the mathematician much of it is elementary, though not by any means all. Its importance seems to me self-evident. There are plenty of instances of pension schemes and insurance enterprises which have failed because of neglect or ignorance of the mathematical principles involved, and the importance of such enterprises to our security and happiness when wisely administered needs no advocation. Without the mathematics of the actuary and the so-called mathematics of finance I believe that such administration would be exceedingly difficult, if not impossible.

There has recently come to my attention an application of the theory of statistics of a different sort which has interested me much and which indicates, it seems to me, a type of industrial question which can be answered satisfactorily by means of statistical theory and perhaps not so answered by any other means. For some time past one of my colleagues, Dr. Walter Bartky, has been associated with a very large manufacturing company as a consulting statistician. The theories with which he is engaged are theories of sampling whose purpose is to provide methods of testing economically and effectively the product of departments or machines which turn out duplicate pieces in large numbers. Shewhart and Fry, of the Bell Telephone Laboratories, and perhaps others also, have studied questions of this and similar character, but all these efforts to apply statistical methods to testing problems are, I think, of comparatively recent date. The technical information which I have comes largely from Dr. Bartky and I am much indebted to him for it.

I can not describe the methods involved in detail, but I can perhaps indicate as an illustration one of the simpler questions which can be satisfactorily answered. Suppose that a department or group of machines is turning out pieces in such large numbers, perhaps hundreds of thousands, that inspection of the entire product is economically impossible. The operation of the department as checked by an inspection department will not be perfect, but will in the long run produce a percentage of defective pieces which can be determined. For manufacturing reasons it is not advisable to approve a product containing more than a certain percentage of defectives. This percentage is called the tolerance percentage and is usually small, from one tenth of one per cent. to five per cent. The pieces come through the process of manufac-

ture in uniformly numerous lots, for each of which a number of defectives, determined by the tolerance percentage, is permissible. The numbers given in advance are then three: (1) the average per cent. of defectives produced by the department in the long run, (2) the number of pieces in each lot, and (3) the maximum number of defectives tolerated in each lot. The statistician must determine from these numbers the size of the sample to be drawn for inspection from each lot, and an acceptance number, as it is called, of defectives for each sample, which will indicate in nine cases out of ten those lots which have more than the tolerance number of defectives. Furthermore, this determination must be made in such a way that the total number of pieces inspected, or what is the same thing, the total inspection costs, shall be a minimum.

The probability formulas involved seem to be simple enough, but the numbers occurring in them are so large that it is quite impractical to compute their values without the use of approximations. The discovery and analysis of these approximations and the careful justification of them constitute the mathematical difficulties of the problem. It is hardly necessary to add that when lots detailed for inspection are determined by a multiple sampling process, or when the piece produced is only one part of a more complicated product, or when the flow through the department is regarded as continuous instead of lumped into lots, the problem may become mathematically much more complicated.

It may be interesting to you to hear an estimate, which is not my own, of the possible financial significance of the application of these methods. The cost of producing a single chart for the guidance of a department of inspection may in some cases be as much as several thousand dollars, and the annual cost of a statistical department may run as high as fifty thousand dollars per year. But the total costs of inspection in the concern of which I am speaking, for problems which might be susceptible to the mathematical theories of sampling processes, may be estimated roughly at three million dollars per year. Of this amount the mathematicians might hope to save one quarter at least and possibly one half. The sampling costs in one department, where methods not yet perfect are in operation, have been reduced, with an actual gain in efficiency, from one hundred and twenty-five thousand to one hundred thousand dollars per year. The total inspection costs which might be amenable to such savings in a larger group of affiliated companies can probably not be calculated with accuracy, but I am told that a conservative guess would be fifteen million dollars per year. These totals are somewhat incomprehensible to an individual mathematician like myself who jingles only silver, and at times only keys, in his pocket. I enjoy the sound of them and should like to hear them talked about frequently, and confirmed perhaps from several sources.

Of the relative effectiveness of mathematical methods as over against surmises in statistical problems I have no doubt whatsoever, and I know of no more appropriate applications of statistical theories than problems of the type which I have just described. If the sums involved are as large as they seem to be I can conceive of no poorer policy than to leave the solution of such problems to foremen of departments, or to the common sense or business judgment of executives who have limited mathematical experience. They are clearly mathematical problems and should be solved by mathematical methods, in so far as mathematical methods can be devised to

apply to them and mathematicians with research interest and experience induced to take an interest in them.

I have so far said very little about the applications of mathematics in engineering and I hesitate much to do so before an audience including many who would be much better qualified to speak upon this subject than myself. But I will try to give you some of the impressions of a pure mathematician in the presence of the mathematics of the engineer.

I find that practicing engineers, and members of engineering faculties, frequently show great reluctance in admitting that mathematics plays an essential rôle in engineering problems, though the books on engineering seem to tell a different story. However much the engineer may prefer to avoid thinking in any except the most intuitive mathematical terms, yet there is after all an irreducible minimum of mathematics in his science, including principles of the calculus and some of a more advanced type, without which he would be very uncomfortable indeed, and which are in fact in some form or other indispensable to him. I was much interested recently to find in print an exposition of the engineer's mistrust of mathematics, in the last chapter of a well-known book on the strength of materials. The sentiments there expressed are not my own, and the comments on mathematics there made will not all stand the test of accuracy, but it seems to me that the attitude of mind exhibited is somewhat like that of other engineers with whom I have conversed about the matter. The keynote of the chapter is the adjuration to use common sense in avoiding mathematics where mathematics is inapplicable, and in avoiding tests where testing conditions do not properly duplicate the conditions under which the results of the tests are to be applied. This is wisdom to which I should heartily subscribe. But in deference to mathematics I should like to add one further principle. It is that common sense should also be scrupulously avoided in places where common sense does not apply. No amount of common sense unaided can predict the motions of the heavenly bodies, or construct a range table, or prescribe the most economical and effective methods of testing under conditions such as I have described above.

That mathematics may sometimes be a guide and not merely a tool in engineering research is well indicated in a very interesting letter which I received recently from Dr. T. C. Fry, of the Bell Telephone Laboratories, and which I will translate in part to you in my own words. If there seem to you to be discrepancies with the facts in my account please attribute them to me and not to him.

Pupin's paper of about 1900 on loading of electrical circuits marks an epoch in the development of telephony. Heaviside had suggested the possible advantages of such loading, but Pupin reduced these crude suggestions to exact form by means of a mathematical investigation, and checked his results experimentally afterward. I may say for myself that one of Pupin's papers of this period, which I happen to have in my library, is an exceedingly interesting application of what mathematicians call a boundary value problem for a differential equation of the second order.

Alternating current theory is in fact the theory of linear differential equations of the second order. Modern developments in this domain are due to Kennelly, Steinmetz, Carson, Bush, Wagner and Gustav Mie. I infer from Dr. Fry's letter that the applications of the theory to more complicated electrical networks lead again to boundary value problems of somewhat the same type as those studied by Pupin.

The transmission of more than one telephone message over a single pair of

wires is accomplished by means of wave filters designed upon purely mathematical developments by Campbell, Carson and Zobel. The enormous economic importance of this application is clear if one remembers that a single pair of long distance wires now carries as many as three telephone conversations and twenty telegraph messages all at the same time.

The story of the first submarine cable across the Atlantic is dramatic. Lord Kelvin, who was plain Mr. Thompson at the time, was the scientist involved. On the basis of reasoning that was at least indirectly mathematical he concluded that the cable should be worked at lower potentials than those which were proposed by the chief engineer of the project. After the cable was finally completed the engineer acted upon his own judgment and the cable was utterly ruined inside a week.

Within the last two years a new epoch in submarine cable telegraphy has begun as a result of the use of the new magnetic material, permalloy. The chief credit must go to permalloy, but it would have cost enormous sums of money to find out the things which Carson and Gilbert deduced mathematically. A pure mathematician might not approve of all the details of the analysis used, but the cables have been laid, and they transmit four times as many words per minute as the best of the old sort.

This is an impressive list of the achievements of mathematics in a single domain, indicating how intimately interwoven that science is with the applications of electrical theories in the industries. I am greatly indebted to Dr. Fry for it. I have omitted with regret the applications of statistical theories which he mentioned in his letter, in some of which he has himself been intimately engaged, because I have already spoken at considerable length upon that subject.

There is one further type of applied mathematics which I should like to mention. The applications of mathematics which I have hitherto cited, and doubtless many others immediately important for the industries of to-day, depend for the most part upon the theory of functions of a single variable. No sharp line of demarcation exists between them and the more advanced theories which I have in mind at this moment, but the latter may be roughly characterized by the fact that they involve functions of several variables instead of a single one. Among them are included the mathematically more intricate portions of the theories of gravitational attraction, thermodynamics, hydrodynamics, elasticity, sound, and electrodynamics with its related theories of light. The whole lot may be fairly described by the single title, the mechanics of continua. It is characteristic of problems in this field that they lead to partial instead of ordinary differential equations, and the mathematical problem which most frequently emerges is that of determining a solution of a partial differential equation which is well defined in a certain region of space, and which is determined uniquely by properties on the boundary of the region prescribed by the physical question whose answer is sought. Examples of problems of this type are the determination of the potential functions for a gravitational field, the determination of temperature variations in a field when temperatures at the boundary are assigned, vibrations of strings and membranes, the determination of potential functions for electrostatic or magnetic fields, and many others. I must admit that these problems have a great fascination for the mathematician, irrespective of their applicability in the industries or in neighboring sciences, and I am willing to make this admission in spite of the fact that the yielding to such fascinations is sometimes implied to be a fault rather than a virtue.

Much work has been done by mathe-

maticians in the domain of boundary value problems, but an enormous amount remains to be learned about them, and the subject will probably never be exhausted. The further development of methods of computation which will make theoretical results of immediate service in the applications is highly to be desired. Until such methods are known we can not hope to convince fully the practitioner of the importance of these theories from his standpoint. That the more advanced mathematical theories have great value in the interpretation of phenomena apart from numerical applications, however, seems to me well illustrated by the avidity with which the physicists have recently seized upon the theory of relativity, and by their restless searching for an adequate mathematical explanation of the phenomena of the quantum theory. One by one mathematical devices for this purpose are invented, tested and discarded, with a rapidity which is bewildering to mathematicians and to the physicists themselves. The situation in the quantum theory has been described as analogous to that of the theory of celestial mechanics just before the time of Newton, and it is said that a super-Newton is required to unravel the difficulties in which the physicists now find themselves involved. It seems to be so, and I know of no more likely way for a mathematician to win great reputation at the present time than by entering into this domain. The only difficulty is that ascent to the pinnacle of fame is likely to be laborious and difficult, tenure of equilibrium there unstable, and descent unceremonious. From failures quite as much as from successes, however, the final solution will doubtless be evolved, and if present indications are to be trusted its character is likely to be mathematical as well as physical.

It is interesting to notice that the mathematical quantum explanations have been for the most part developed in Europe. We have at present in America, and have had in the past, relatively few scientists of prominence devoting themselves to the more advanced domains of applied mathematics. We have had no adequately populated school of applied mathematics from whose membership greater minds might be expected at reasonable intervals to emerge. Comparatively recently agitation has been started for activity in this domain, and a beginning has been made. But the sympathetic support and appreciation of practicing mathematicians and engineers, of the pure mathematicians, and of scientists in other neighboring domains is urgently needed.

In conclusion let me set forth the three hopes which I have desired to further in some small way by the preparation of this paper. I am hoping first that the calculus, which is so important in the immediate applications of mathematics to-day, may be presented earlier and more clearly in our college curricula, and that it may become a familiarly convenient tool and friend to the practicing mathematician, instead of a stumbling block and barrier. In the second place, I am hoping that avenues of communication between the industrial and mathematical worlds, numerous and broad and open, may be constructed, and that traffic in ideas and fluidity of adaptation of such ideas may be freely encouraged between the two. My third hope is that we may have in America a well-populated school of applied mathematics with corresponding activity of interest in the applications of mathematics in all their phases, a school which in personnel and numbers shall be comparable with the dignity of our representatives in the other sciences. Beginnings have been made, but encouragement and appreciation are necessary from all of us, even if results achieved

do not fit perfectly into our individual scientific or practical needs.

I have been speaking for mathematics in response to the request of your chairman, and because it is the only science which I could in any way adequately represent. But it would be a very narrow mind, it seems to me, which believed that mathematics, or any other science, has a uniquely fundamental rôle to play in the interpretation of the universe of phenomena about us. The keynote of our age is cooperation, and for the scientist that means cooperation in the restless and inevitable effort of the human race to transform a life of slavery into one of mastery, as far as may be possible, of the natural forces in which we find ourselves immersed. I shall be satisfied if I have indicated with some degree of clearness the desire of mathematicians, as members of a much larger community of natural scientists, to aid in that transformation.

PUBLIC HEALTH

By Professor RANDLE C. ROSENBERGER
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WHEN we become reminiscent and think of the appalling death list attributable to typhoid fever alone, it certainly looks at the present time that many lives may have been saved.

This monster of super Gargantuan proportions with seven (or more) league boots, stepping here and fouling a water supply; again leaving a filthy spot or area for flies to breed; or, for some poor, uneducated people to come in direct contact with and thus spread infection, we believe, and the statistics also prove, that this monster can be held in check.

C. Macfie Campbell in his monograph on delusion and belief says that "man is no longer impotent in the face of devastating forces of disease, but by mastering the nature of these forces and studying his own bodily resources he has erected cunning defenses."

The "mastering the nature of these forces" and "erecting cunning defenses" has been the result of problems solved principally by sanitary engineers.

An engineer is described as being one who carries through an enterprise or artful contrivance.

The artful contrivances must be inferred to mean those that are performed or are characterized by art or skill or both.

Again, an engineer is described as being an efficient manager, so, taking the meaning of the terms we have in the most liberal form an engineer is one who carries through or manages by skill or art, or both, some enterprise or feat.

This enterprise may be one that comprises the selection of a water supply of a town or city; it may mean the disposal of sewage, garbage and other like wastes; it may mean the disposal of, or disposal and recovery of irritating or poisonous dusts and fumes; it may mean the perfection of a model building or factory where workmen or laborers may work in safety; it may be the perfection of an apparatus or equipment for the proper handling of such foods as milk, eggs, gelatin, etc. Besides these projects we may include the methods introduced for the destruction of mosquitoes and for their eradication; insuring the safety and purification of the supply of cows' milk as well as methods for the prevention of disease and death in the various industries.

Thus it is seen that these multiplied engineers comprise a great army tending

in the main towards the prevention of disease and prolongation of life from many angles.

The results attained by engineering feats for public health are numberless and diversified, but particularly outstanding are those brought about where certain diseases have been stamped out and eradicated, in some instances, forever.

In the early days when infectious diseases were thought to be brought about by miasms or humors, where pioneer work was instituted, especially in the purification of water and disposal of sewage, these pioneers for health were indeed great engineers for the cause of humanity.

The work of Virchow in Germany was a most noteworthy example of sanitary engineering, and in our own country the efforts of Osler in preventive medicine, especially in the infectious diseases, were inspirational in what has been established along this line.

Naturally, one of the greatest and most widespread beneficent engineering projects is the establishment and maintaining of a pure, wholesome, safe water supply.

This, one must bear in mind, takes into consideration the actual or absolute source, and while directing it into its proper channels for household consumption, it must remain unpolluted either from an animal or human source.

It must also be borne in mind that a reserve supply of this water must be housed or stored in reservoirs, which reservoirs must be constantly inspected and really guarded to prevent any contamination or pollution of this food stuff.

This, in my mind, is a great and wonderful engineering feat, to harness a water source and shed miles and miles away from a town or city, and prevent its contamination up to the actual consumption of the product!

On the other hand, the purification of a polluted or contaminated water by mechanical and chemical means, though it is a measure of making the water safe from a bacteriological standpoint, is not nearly such a wonderful feat as the actual selection and maintaining of a pure and undefiled water for all household purposes.

Together with this problem may be linked the swimming pool, which to-day, thanks to sanitary engineering devices, keeps the water as clean as the water we drink.

Coincident with the purification of water and equally important to our health is the proper and safe disposal of sewage and wastes.

The habit of dumping garbage and sewage into the ocean or inland lakes is a makeshift and should not be tolerated in any large community.

Nuisances no doubt result from such practices and diseases may be disseminated.

At the present time any first-class municipality should erect and maintain proper disposal plants for sewage and wastes other than sewage. The installation of incinerators or destructors for rubbish is the surest method of disposal.

The Beccari system of garbage disposal is a most ingenious and desirable method of ridding municipalities of this offal. I think it is also a most wonderful achievement in the eradication and prevention of hookworm disease. Naturally, this has been primarily a problem of education, but it has as well been an engineering problem, in the disposal of excreta and the prevention of soil pollution.

Thousands upon thousands of lives have been saved and others bettered by the methods laid down by the International Health Board in the management of the hookworm problem throughout the world.

In industries, where arise quantities of dusts of many metals, where vapors and gases in the manufacture of manifold products are generated, an ingenious process for the removal of these dusts and gases and their recovery from the working atmosphere is abundantly and successfully accomplished by means of the Cottrell electrostatic process.

The wearing of masks, goggles and helmets are a decided and added protective measure against these poisonous and offensive suspended materials, together with exhaust devices.

From many industries the air is polluted by smoke and particles of carbon, and at the present time devices have been perfected for the recovery and disposal of these gases and solid particles which otherwise would be deleterious to health.

In these days of subways and tunnels great engineering problems take into consideration the safety of travel, by ridding the atmosphere of vitiated and poisonous gases and installation of devices for proper ventilation. I do not think it at all amiss if mention is made of the efforts of municipalities in the adoption of devices trying to solve the question of safety in the momentous question of traffic problems.

Apart from the dust and gas removing appliances, one of the greatest engineering procedures in industrial hygiene and medicine is the physical examination of prospective workers and the periodic examination of those accepted for such work. Were it not for these overhaulings many grave insidious forms of poisoning would take place; or many fatalities would occur in individuals engaged in the construction of foundations for bridges or tunnels, if the workers were not properly selected.

Even in time of peace this method of selection of healthy and suitable men is going on to keep our quota in the army and navy in fit condition. Apart from this phase, the suggestion for periodic health examinations of individuals in all walks of life is an instance of conservative engineering.

Again, regarding the industrial worker, think what the engineer of health has done in supplying the industrial worker with a workshop or room, with the so-called sunlight walls and up-to-date ventilating systems! Natural sunlight, right at his loom, his desk, his grindstone, his furnace or his workbench. No dim lights, no unguarded stairways, no unguarded belts or saws!

In their stead we have proper equipment, proper tools, efficient safety devices for all sorts of machinery; rest periods and real rest rooms for relieving tension of all kinds.

Another problem in industries as well as in ordinary walks of life is the one pertaining to tuberculosis. This was another question that interested Osler very much, and he was among the first to put forward plans and organize for the study and prevention of this disease.

Trudeau in Saranac was, as we know, a pioneer as well as engineer in the outdoor fresh-air treatment for this disease, and from that modest but earnest effort there has arisen the numberless sanatoria for the study and treatment of this plague.

From the progress noted in the institutional care of these cases we know that we are getting the better of the disease.

To-day we have also the pertinent question of engineering a project where the children of tuberculous parents may be segregated from the parents where ignorance regarding dissemination exists and the environment is not suitable for proper development.

In a number of instances where tuberculosis was said to have been brought about by dusty occupations, it was found by surveys made of the industries, as

well as the homes of the workers, that the home life and environments were far more to blame than the industry itself.

We are all familiar with the beneficent action of the ultra-violet rays as a bactericidal agent, and to-day the administration of sunlight both natural and artificial to patients with tuberculous diseases is followed by wonderful recuperative effects in these cases.

Is it not also a wonderful procedure at present, where the patient is treated in a room which is lighted by panes of glass which filter out the red rays, and thus the beneficial rays play upon the diseased body for any length of time desired!

Passing from the industrial workers our next consideration is of one of the most widely used foods and one that we can not at present curtail. I refer to milk; its production; its handling; its present treatment; its preservation, distribution and consumption. No one will gainsay that, next to mother's milk, it is the most important food for the infant and growing child.

To-day we are making wonderful studies in the adoption of the so-called accredited herd system in the dairy industry and until this is generally, or I might say, nationally adopted, our attempts at proper pasteurization must be upheld to the letter.

The farmer is in some cases the stumbling block in testing his cattle against the disease, tuberculosis; but he must be taught, the public must be taught the danger from one diseased animal (which looks particularly healthy) in a herd of five or six cattle, or in a herd of fifty or more.

The tuberculin test is the best method we have at present in the detection of tuberculous disease in cattle, and where no naked eye lesion of the disease is apparent in a reacting animal, an unenlightened person may condemn the test.

It is true we do have such reactions occurring in some animals, but microscopic studies reveal the disease in most cases.

If we can not at present obtain our milk supply from animals free of disease, then our next best procedure is the proper pasteurization of the product. That is, the milk must be held at 60° C. for at least thirty to thirty-five minutes, although the laity does complain that the cream line is not as deep in some as in another dealer's milk.

The handling of milk to-day from the many receiving stations in the country districts in the thermos-bottle-like cars and the pumping of the milk into these cars does away with a great deal of dirt and other extraneous materials which reached the product in the old methods of handling.

After an inspection of many up-to-date receiving stations and pasteurizing plants, it is my opinion that from the outlay of money for equipment of the buildings, with up-to-date machinery for the pasteurizing and bottling and the distribution of milk, these dealers are doing their utmost in conforming to the rules laid down and the suggestions made by local as well as state boards of health for the proper pasteurization and measures for the proper distribution of a safe milk for all purposes.

The same words of commendation could be made regarding the making of milk products, such as the various brands of dried milk upon the market. These are engineering feats pure and simple and all done for the maintenance and preservation of health.

The examination of those engaged in the dairy business, as to their cleanliness, their present health, their previous health and the possibility of a carrier, as of the typhoid bacillus, is another procedure in the prevention of the spread of infections.

The addition of the mechanical milker to the dairy is another step in the hy-

giene of the dairy, but care must be exercised that it be cleaned properly and receive attention such as any other mechanical device.

Other foodstuffs might be mentioned and one, I might dwell upon for a moment, is gelatin.

I remember, years ago, when examining the finished product that millions of colonies of various bacteria and moulds would be encountered. To-day, through proper handling of the product, the disposal of dusts and the refrigeration method of cutting the ribbons of gelatin, a sterile product is produced quite regularly without the addition of any acids or preservatives.

Passing from foodstuffs, we will next consider engineering in medicine toward the prevention of diseases brought about by insect dissemination.

We need not again repeat, at this time, the names of the heroes who gave their lives in the interest of science, to prove upon themselves or working directly with the diseases, that dissemination takes place by these agents.

The most wonderful discovery, in my mind, was in the yellow fever problem, where it was proved, after thousands of lives had been sacrificed, that a certain mosquito must bite a person before he contracted the disease.

The final steps in the completion of the Panama Canal could not have occurred, except for the epochal study in yellow fever and its dissemination.

Of course the dissemination of malaria by other mosquitoes was known, but the disease was not so fatal as yellow fever.

The knowledge gained by tracing the dissemination of diseases by insects naturally led to the destruction and eradication of these pests and the culmination of many engineering feats apart from the Panama Canal were accomplished.

The exact knowledge regarding the distribution of the tsetse fly is another point which from the standpoint of cattle raising with its many side issues, and the propagation of disease in man, speaks very well for the sanitary engineers in keeping these areas free from these flies.

The method of treating the surface of ditches, pools and streams with crude oil and various mixtures of crude oil for the suffocation and poisoning of larvae of insects was indeed a wonderful engineering project. Imagine what a feat it is, where a dust containing one part of arsenite of copper per hundred, applied to breeding places of anopheles or malaria-bearing mosquitoes, acts specifically upon the larvae of these mosquitoes but does not affect the larvae of other varieties or the larvae of flies.

The method of distributing poison from an aeroplane was ingenuously novel, and according to reports very successful against the destruction of these disease-disseminating insects, as well as others.

Going hand in hand with the dissemination by insects is the possibility of rodents spreading infection, either by their bite or by harboring insects and other parasites. This has led to the building of ratproof buildings, such as storage houses, which has kept the propagation of rats down considerably.

Now, regarding one big phase of disease prevention, though it is in the consideration of little things—children—the methods to-day that have been brought forward in the curing, as well as in the prevention of rickets by ultra-violet rays and increasing the potency of cod liver oil is an epochal achievement. The organization and establishment of various societies for the prevention of tuberculosis and the prevention of cardiac disease stand out as two very important links in the chain of engineering for health and prolongation of life.

While compulsory vaccination against smallpox absolutely protects us against

epidemics of this disease and the antitoxin of diphtheria and antitoxin of tetanus prevent and cure these diseases; and the administration of various convalescent sera against communicable diseases, while not specifically recognized nor spoken of as engineering problems yet, when analyzed, are just as great engineering feats and accomplishments in the prevention of diseases as the purification of the water supply or the proper disposal of infectious wastes or poisonous dusts.

Mention alone can be made of the work that is being done by our fellow scientists, the chemists. I say chemists broadly, because by specializing any branch of the science we certainly perchance miss one or two of them.

These busy bees of our life delve into every phase and question of our living; they dissect, inspect and recommend the things we eat, the things we wear and peer into the most important aspects of light and heat.

Chemical engineers are turning out products every day, some of which never existed before, and determine means of water purification for the sanitary engineer; and, for the civil engineer, testing water-purifying substances to prevent corrosion of boilers and pipes and thus bring up a question of life saving and conservation.

We are also indebted to them for the perfections of the X-ray machine, for medicines and appliances which alleviate suffering and make human lives happier.

One of the many things which is being worked upon now is an apparatus or appliance to enable the deaf to hear and the dumb to speak.

In summing up the results of the various agencies at work in the prevention of disease, in protecting the workmen and in teaching the methods of proper living to our growing population, it is manifest that the corps of engineers is a large one, the sanitary engineer, the chemist and the physician being especially prominent in playing a part in the health of the world to-day.

The public must be educated and this can not be done by posters with grotesque, fanciful and sometimes childish or silly legends or slogans. The education must begin with the child, at home as well as at school, with practical demonstrations.

In many instances parents are taught by their children who have gotten lessons in cleanliness, health and well-being from their teachers at school.

A word of praise, which I think is well deserved, should be given to the school teacher, and the social worker as well, who many times have had to act as parent and teacher to many children who lack this very important link in the developmental years of their lives.

PSYCHOLOGY

By Dr. J. McKEEN CATTELL

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THE alphabetical order of the sciences in this discussion places astronomy first and psychology last. This is also the historical order of their development. The facts of astronomy, based on observation and measurement, formed an organized body of knowledge at the earliest stages of civilization. The calendar and the measurement of time, the use of observations of the heavenly bodies in surveying and navigation, not to speak of soothsaying and astrology,

were among the earliest applications of science. Psychology has become a science only in the course of the last fifty years. I have special interest in the circumstance that the first professorship of psychology was established at the University of Pennsylvania in this city thirty-eight years ago. Applied psychology and psychological engineering are in the main problems of the future.

While psychology is the most recent of the sciences on this program, its subject-matter has long engaged both philosophical speculation and the interest of the every-day man. As we now see it, or at least as I see it, psychology is the science of how individuals think and act. This was the principal concern of primitive man, as indeed it is of the lower animals. Each is interested before all else in his own mental life, in his own behavior and the behavior of others. Satisfaction of desires and wants, aversion to pain and danger, exist at the outset of life. The control of behavior also begins early in the animal series and in the new-born individual. Young animals learn by experience to adjust their movements to satisfy their needs, and with the same object they seek to influence the behavior of others.

When such is so clearly the case, it may seem at first sight surprising that the sciences, both curious and useful, of matter and energy should have had an earlier origin and a more systematic development than the biological sciences, while psychology is only now taking its place among the descriptive sciences and has witnessed but its first beginnings as an applied science. The explanation is in part the difference in complexity and stability of the objects of the several sciences. Matter is plastic to experiment and measurement; minds and behavior elude experimental and quantitative methods. The known performance of the solar and stellar systems since the beginning of astronomy is less complicated than the play of a child for a day.

Another reason for the later development of psychology is that it is easier to satisfy minds and to control behavior by altering the environment than by altering individuals. The savage could shoot an arrow from a bow or move a stone with a lever more readily than he could strengthen his own right arm. He could obtain food better by planting corn than by developing his skill as a hunter. And so it is to-day. By increasing economic production and improving the distribution of wealth, we can do more for the welfare of people than by trying to teach them to be virtuous and wise.

Engineering has a certain analogy to psychology in its early use and its late development into a science and a profession. As psychology may be traced back beyond the first use of language as a means of communication, so engineering is as early as the first use of tools. Engineering works of great magnitude were constructed by the Egyptians and the Romans. But in the modern period for six hundred years theology, law and medicine were the schools of the university. The first schools of engineering were established only a hundred years ago. In this short period engineering has become the profession that is most useful and most securely based on science.

A painting in the library of the Engineering Society's Building in New York bears the inscription: "Engineering—the art of organizing and directing men and of controlling the forces and materials of nature for the benefit of the human race." According to this definition, chosen by engineers, the relations between engineering and psychology are close. The selection, training and directing of men are problems of applied psychology; it is also for psychology to determine what does in fact benefit the human race. In using the forces and materials of material nature engineering has become an exact science; in its relation with human nature engineering

works by the rule of thumb and will continue to do so until it can use an exact science of psychology.

On the one hand, engineering is dependent on psychology; on the other hand, the objects of applied psychology, namely, the control of the behavior of individuals, have been advanced by engineering, invention and industry to an extent incomparably greater than by anything that psychology has been able to accomplish. The applications of science, by quadrupling the wealth that each can produce and by doubling the average length of life, have completely altered our civilization and the way that each of us reacts to it.

The economy of labor and of life which science and invention have wrought has abolished slavery and serfdom. It has made unnecessary productive labor by children and has made possible their universal education. The wealth of society is now sufficient to support adequately every child, to give it the education that opens the gateway to the career for which it is fit, to provide equality of opportunity and a true social democracy. Applied science, based in large measure on scientific research whose utility was not at the time obvious, has been the cause of the political and social institutions that we have and of the lives that we lead.

It appears that engineering and the applications of science have done more to control our behavior than efforts made with this object directly in view, such as those of the churches, the schools, the courts and the state. It may be argued plausibly that the ten commandments would have been broken no oftener, that the precepts of the sermon on the mount would have been followed no less rarely, if the churches had never existed. It may be that it is as futile to herd children in pens to teach them their R's as it would be to use similar methods to teach them to walk and to talk. It is quite possible that there would be no more crime in the world if courts and prisons had never been invented.

These partial failures to alter human nature by direct appeals to consciousness are quoted to emphasize the thesis that applied psychology is concerned with the total relation of the individual to the environment. We can try to alter the individual; but we can accomplish more by altering the physical world in which he lives, perhaps most of all by altering the relation of an individual to his surroundings. As modern medicine has made more progress in the diagnosis of disease than in its cure, so psychology can determine the intelligence of a child, a soldier or a congressman more readily than it can increase it. In like manner as medicine and public hygiene can do more for the health of people by providing surroundings that are sanitary than by curing diseases that have been contracted, so psychology can do more by placing individuals in surroundings where they will act in the way that is wanted, than by attempting to change individuals so that they will act in a more desirable way.

The control of thoughts and behavior has been undertaken by the churches, the schools, the laws and the rest in order to accomplish definite results that are regarded as desirable, but they have largely failed because it is difficult to change human nature. Individuals at birth have definite constitutions, and will react to their surroundings in accordance with them. What we can do is to place them in situations where they will behave as nearly as their constitutions permit in the way that we want. By changing the surroundings we control behavior most effectively. This is what engineering and applied science have done, but they have advanced without special reference to the kind of mental life and behavior that will follow.

What we need is a science that will coordinate all efforts to alter human nature or to control conduct with the effects of all changes in the environment that alter our behavior or increase welfare. This is the business of psychology; that so little has been so far accomplished does not relieve us of responsibility for the future.

Nearly all psychologists have been teachers, and those engaged in research have nearly all been university professors. It is consequently natural that the first and most extensive applications of psychology have been in education. These have covered a large range of teaching and learning, but have been most exact and useful in selecting children for the work that they can do to best advantage. Probably more than five million tests were made this year in the schools. These tests have great advantages over the usual examinations in that they put measurement in place of opinion and aim to determine what a student can do rather than what he has already learned.

The most extensive use of psychological tests in the United States outside the schools was in the army where some 1,800,000 recruits were examined. Although the tests used were not adjusted to determine who would make the best soldiers, they proved useful in selecting objectively those at the upper end of the curve of distribution who were officer material, those at the lower end who were unfit for any kind of service. Most army officers were converted to the utility of the tests, which is certainly strong evidence in their favor.

The proved usefulness of psychological tests in schools and in the army might be expected to lead to their general use in industry, but this is not yet the situation. In Germany tests are used in the selection of apprentices for a number of trades; in Paris taxicab drivers are required to pass an examination by the municipality; in the United States tests are given by a number of corporations. The intelligence tests of the school and army type are especially applicable to clerical workers. I have asked a number of people of competence in business and affairs how much they think production would be increased if each individual from the moron to the genius were given the work that he could do best, were trained in the best way to do it, and the conditions were made such that it could be done to best advantage. The estimates vary from ten to a thousand per cent., which represents a large range of ignorance, say the difference between an increase of the wealth produced by the nation of from ten to a thousand billion dollars a year. Surely it would be worthwhile to determine which of these estimates, if any, is correct and then to adopt the measures necessary to produce the additional wealth, with a proportional increase in contentment and happiness.

Psychological experiments have been carried forward in many directions which directly concern engineering and industry, and in turn engineering and industry have developed methods which contribute to psychology, such as the Taylor system, employment management and industrial engineering. Among innumerable problems that psychology, engineering and industry have in common are the desirable hours of labor; the most efficient movements; interest, enthusiasm and imitation; all conditions favorable or unfavorable to work or other forms of activity, including ventilation, heating and lighting; food, alcohol, coffee and tobacco; rest, play and sleep; posture and strain in employments; conditions of fatigue and safety. An Institute of Applied Psychology in England and a Psychological Corporation in the United States have been established to forward research in psychology and its applications. Our organization

has the cooperation of practically all American psychologists with branches and stations in forty-two states. We can thus look for the rapid development of the useful applications of psychology and its closer coordination with engineering and industry.

As psychology and engineering are closely interwoven, so it seems to me are the useful sciences and the sciences called in this program "pure." There is a clear distinction between the applications of knowledge that we have and the acquirement of new knowledge, between the physician who uses known remedies to alleviate disease and the pathologist who advances knowledge of causes and remedies, between the builder of bridges and the engineer who makes new designs. As there must be division of labor between the psychologist and the engineer, so there must be among mathematicians, physicists and psychologists who on the one side seek to advance science without regard to its applications and engineers who on the other side find new ways of applying knowledge. But the methods are the same and the men are sometimes the same.

Kelvin and Pasteur are notable examples. The former was a great mathematical physicist and at the same time made inventions and engaged in the practice of electrical engineering. Pasteur founded the science of bacteriology in direct work on practical applications —the fermentation of beer and wine, the diseases of silkworms, chicken cholera, anthrax, rabies. In like manner Lister discovered antiseptic surgery, and the great German pathologists, Koch, Behring, Ehrlich and the rest, made their contributions at once to science and to human welfare. As Pasteur remarked: "There is no greater charm for the investigator than to make new discoveries, but his pleasure is heightened when he sees that they have a direct application to human life."

In the short interval at my disposal it has seemed better to discuss some general relations between psychology and engineering rather than to undertake to describe specific cases of the applications of research in psychology to engineering practice. A review of psychology in industry by Dr. M. S. Viteles, of this city, printed in the *Psychological Bulletin* for November, quotes 360 recent publications. A critical summary of these or a detailed review of almost any one of them would take us beyond the limits of the present discussion. What it seems most worthwhile to emphasize is the close relation and the mutual interdependence of psychology and engineering. The body of knowledge is a whole like the human body. Aristotle said long ago that a hand apart from the rest of the body is no longer a hand. So each science exists in large measure in relation to others; psychology and engineering are members one of another.

WHAT TRANSPIRES IN THE KINGDOM OF RESEARCH

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IT would be curious to know just how the intelligent layman regards the minutiae of research, how he thinks that the investigator puts in his time. To the investigator himself such laymen appear to regard research as an esoteric province of flaming magic wherein ordinary men divest themselves of monotony and routine, slip on genius like a smock, then discover, enlighten and synthesize higher civilization. Yet the investigator very often feels like some inept animal roaming a strange and forbidden environment, condemned to entirely too much routine and proceeding, not very rapidly, nowhither. He does not, customarily, sense the glamor which induces the layman to declare so glibly that "research must be very interesting."

Just what is research, anyway? Precisely how do these bewildered primates carry on in their sacred precincts? There is much plausible reason for ignorance on the part of the intelligent layman because no one seems yet to have thought of the very simple expedient of tracing out for him the pursuit of "truth" in a specific instance. This exposition should be both diverting and enlightening to intelligent people who often wonder what on earth investigators actually do in their laboratories, besides smoke cigarettes, that is. The writer will therefore endeavor to give in common or garden language an authentic account of one investigator's travail as he sought to solve a problem. His slight triumphs, his frequent and painful rebuffs seem not devoid of interest to the gentry and intelligentsia. The writer has intimate knowledge of the work outlined herewith.

Since all present-day research problems are of necessity small corners and fragments of much larger problems, a slight introduction will be necessary for the understandable presentation of this investigator's actual work. Since this introduction will deal with a phase of nutrition chemistry which is too often inaccurately presented to the public, but which is interesting and informative, and since its presentation will clearly illustrate how an investigator finds and attacks a problem, this preliminary seems justifiable.

As Fischer discovered, the proteins we eat do not enter as such into our living tissues. In fact proteins can not normally penetrate the adult intestinal wall. They do permeate it in early infancy, for the very first milk secreted by a mother, the colostrum, containing valuable substances protective against infant diseases, presents these substances, or "antibodies," in a protein named "globulin." Globulin has to penetrate the intestinal wall in order to do its protective work. But when a protein gets through the intestinal wall of an adult it simply starts trouble; it is toxic and gives rise to symptoms of poisoning each time this leakage occurs.

Thus some persons can not eat eggs without subsequent illness, due to the fact that their intestinal walls are permeable to egg protein, which, entering their blood stream as such, causes illness. This phenomenon is called "allergy" and it is also responsible for such diseases as asthma and hay fever when the protein permeates the respiratory tract.

Proteins are, therefore, broken down in digestion by enzymes like pepsin, and

the proteins of the tissue are rebuilt from these simpler compounds, somewhere and in some as yet unexplained fashion. In fact an animal is very particular about the character of its tissues and of its secretions—milk, for instance. The constitution of the proteins in an animal's tissue differs from animal to animal, from organ to organ. Indeed, there is constantly accumulating evidence that the chemistry of bodily tissues differs from individual to individual. Biological tests lead us to think that the structural proteins of each species of cell have highly individualized peculiarities.

It is highly probable, then—for there is also room for a wide variety of microscopical variations, too, that the proteins of no two humans ever have precisely the same composition. It is not pure speculation either to extend this diversity to such things as brain and nerve tissue, an elaboration which may account for many personal idiosyncrasies, for fixed ideas, beliefs, prejudices and relative immunities to reasoning.

How is such infinite diversity produced? Proteins are made up of smaller units called "amino acids." These are the "building stones" of all body tissue. There are about twenty of them. Ingested proteins are broken down into amino acids during digestion; as such they permeate the intestinal walls into the blood stream. Then, as this red medium, which is to us precisely what sea water is to lower living organisms, bathes our living cells, the cells, with astounding selective accuracy, extract from it precisely the particular amino acids they need to rebuild the tissue in their immediate vicinity. For cells are simply chemical compounds endowed with the capability of reproducing themselves.

Tissue proteins are, then, very complex chains of amino acids hooked together. As Leathes, the physiologist, recently pointed out in the *Lancet* (August 7, 1926) if you allow for a chain of approximately fifty links (not a tremendous sized protein molecule at all—in fact, one of modest proportions) and if you assume the existence of twenty amino acids, each one capable of appearing at any point in the chain, and of being repeated at any other interval therein, you soon begin to deal in possibilities of variation into enormous figures. Suppose one kind of amino acid recurred ten times in the chain, four recurred four times, and ten recurred twice. You get 10^{48} possibilities of permutation. The span of the universe is three hundred thousand light years. This figure, even expressed in Ångström units, is less than 10^{48}. In short, the possibilities for variation in the protein molecule of quite ordinary complexity almost approach infinity.

In spite of what may be found in the press it is an actual fact that the exact function of most of the individual amino acids is to-day unknown. We can not tell how most of them limit the organism by their absence from our food. One of them, glycocoll, can be synthesized by the human body, for casein, which lacks glycocoll altogether, and yet proves to be a complete protein for nutrition. Perhaps other amino acids, like alanine, can also be synthesized by us. We do not know, so ignorant are we of our own chemical reactions.

We do know something definite about the function of five amino acids, namely —tryptophane, lysin, histidine, arginine and cystine.

Zein, the protein of corn, lacks both tryptophane and lysin. Willcock and Hopkins found that animals died in a torpor when zein was the only protein fed them. The addition of pure tryptophane to zein enabled the animals to live (*i.e.*, established maintenance) and the addition of lysin enabled them to grow. Adding tryosine, another amino acid, had no effect whatever. Hence trypto-

phane is absolutely essential to life, lysin is essential to growth and tryosine appears to be quite dispensable.

Osborne and Mendel, excellent but too little known investigators, assuming that gliadin (the protein of wheat and rye) contained a negligible amount of lysin (.16 per cent.) concluded that lysin was not needed for maintenance because experimental animals lived on gliadin. But their results were later invalidated by an analysis which showed 1.21 per cent. lysin in gliadin, sufficient for maintenance, anyway. It is interesting also to know that they were, at this time, feeding a "protein free" milk which was later discovered actually to contain one half the maintenance requirement of amino acids for young animals. This all indicates the pitfalls of physiological research. Nevertheless, it is established that lysin is necessary for growth.

Ackroyd and Hopkins, as well as Geiling, all excellent workers of high standing, found that histidine was necessary for growth but declared that arginine could be used interchangeably in its place. Then Rose and Cox, and also Stewart, again excellent workers of high standing, declared that arginine and histidine are certainly not interchangeable, but that histidine itself is absolutely necessary to growth because it functions as a precursor of purines without which animal chemistry is inhibited. Here the layman may be inclined to sniff. But further confirmation has recently been added to the assertions of the last workers mentioned and they seem, just now, predominant.

Cystine was, until Mueller's discovery of another, the only amino acid containing sulfur. It remains the only sulfur amino acid active metabolically (*i.e.*, which enters into the building up of body tissues). It is needed in very small amount, if at all, for maintenance; but it is absolutely essential to growth. Cystine occurs especially in the hair and nails. It is also essential to milk production.

This summarizes all that is really known about the specific usefulness of the amino acids. We need variety as well as quantity in amino acids. A lack of any one of them from the food may become a limiting factor in the biological usefulness of a protein. However, in the customary mixed diet, the proteins admirably supplement each other and thus offset their individual deficiencies in essential amino acids.

We turn now to milk production since the specific problem lies in this field. Here cystine is essential. Milk proteins are of course also built up of amino acids which the cells of the mammary gland unerringly take out of the blood as it perfuses them. Hence if we are really to know the true value of various feeds for dairy animals we must somehow trace these amino acids from the feed, into the blood, thence to the mammary gland and into the milk.

The amino acids constituting various cereal proteins—such as gliadin and zein —are well known. It has also been demonstrated that amino acids occur in blood. Abel at Hopkins got them directly out of the blood of living animals in what he called a vividiffusion experiment. Abderhalden, after hearing of Abel's work, quickly repeated the experiment in Europe on an enormous scale and with changed technique, but the credit is Abel's. We also know the amino acids composing milk casein and albumin. Tryptophane and cystine are prominent among them. Hence feeds deficient in these two amino acids will obviously limit milk production.

This narrows the subject by picking the problem to pieces. There has also been developed an accurate method for estimating the exact amount of one of the amino acids in the blood, namely, tryptophane. Finally, the cow being a docile and well-mannered animal, it is

easily possible to stick small metal tubes simultaneously into her jugular and her mammary veins and to take from these veins exactly synchronous samples of a quart or so of blood. The animal withstands such seemingly drastic treatment without deleterious consequence save a momentary loss of temper. An examination of these two blood samples, of which the jugular is essentially arterial in make-up, demonstrates that arterial blood contains decidedly more tryptophane than exhausted blood on the way back to the heart through the mammary vein. Caught on its return journey after perfusing that gland, its relative deficiency in tryptophane betrays the fact that the mammary gland extracts this amino acid from the blood in order to build up milk proteins. In technical language we say that the amino acids of the blood are the precursors of milk proteins.

That done it becomes obvious that another amino acid should be traced. Cystine was selected, because of its importance in the constitution of milk proteins, and this at last brings us—by so devious and long a road—to the point where an investigator could select an original problem for research. How, then, did he proceed here?

The first question was, of course, can cystine be estimated in blood? Is there a method to determine it quantitatively? He went to the literature. Some forty articles in English, French, German, Spanish and Italian shrieked to assure him that of course cystine can be determined. But, as usual, closer examination raised a doubt as to whether it ever had been determined correctly at all. So many inaccurate articles are published that this disappointment is an every-day inevitability. Prestige gravitated him in favor of a reliable investigator, and an Otto Folin colorimetric method seemed most promising. If a certain reagent perfected by Folin be added to a solution of cystine a blue color is developed which is exactly proportional in intensity to the amount of cystine present. Moreover, it should determine accurately less than a milligram and there are a thousand milligrams in a gram and about thirty grams in an ounce. An instrument called a colorimeter enables the investigator to measure color intensities with extreme accuracy.

But is all the color always due to cystine? May not other substances—glucose, uric acid, creatinine or insulin produce such a color? These must be tried and negative results secured. Then do the reagents themselves in "blank" give a blue color? Yes. Then they must be recrystallized and purified until the blank is colorless. Is the blue color now actually proportional to the amount of cystine present and if so what is the actual range of delicacy in the method? These things must all be tried out experimentally with solutions of pure cystine regardless of what appears in the literature, because so chaotic is the literature and so uncertain in value are many printed articles that the careful investigator can only dare proceed after verifying personally every slightest detail. This is most unfortunate but true. So much ill-done work appears in the very best journals. A detour must also be taken into other methods of determination to be sure that they are as fruitless as they seem to be. This involves reading and digesting thirty more articles.

But after some months the investigator is ready to attempt the determination of cystine in blood. But blood is full of corpuscles and soluble proteins and these must be got rid of before analysis can proceed. How shall they be precipitated? One hundred articles now howl at him in five languages to tell him which procedure is best. He must wade through these, meantime trying to keep

his critical faculty awake. He finds at last no entirely conclusive evidence anywhere that any method for ridding blood of its proteins can be absolutely guaranteed not to take along always a small amount of the amino acids there in solution. Total amino acid determinations mean little, for 25 per cent. of one of the twenty might be lost without ever showing up in a total amino acid determination. Yet that entire 25 per cent. loss might, for all he knows, be cystine.

Then how would ultrafiltration do? That means passage through a collodion (new-skin) membrane under pressure, which gives what is said to be a reliable filtrate for analysis. Forty polyglot articles again assure him of all sorts of possibilities here and he wanders through the maze experimentally a few weeks.

Thus we see him reading and seeking by laboratory procedure. And in a few months he has a method of ridding blood of its proteins which he is reasonably sure does not decrease its content of cystine. He adds pure cystine to blood before ridding it of protein and finds the added cystine all there intact afterwards. That is reassuring, but there is a doubt saying he may have changed the blood reaction in adding the cystine and thus have set up an abnormal condition. He hopes not and passes on.

He makes his first analysis and it is simply astounding. If he can believe it and all this blue color be due to cystine then one third of all the amino acid in the blood is cystine. This is simply absurd. Then has he to do with cystine altogether? Or at all? This leads to a new and more frantic search of the literature—a hundred devious articles in Babel again. The search is for the most likely organic compound to be in blood and to cause that color. Finally a dipeptide (*i.e.*, compound of two amino acids), called glutathione and composed of cystine joined to glutamic acid, seems most likely. Glutathione was discovered, though, by Sir F. Gowland Hopkins, discoverer of the first amino acid, the light of Cambridge University, one of the leading physiological chemists on earth and decidedly a baronet. And the baronet specifically denies that glutathione occurs in blood!

This is a terrific blow. For prestige absolutely blocks the path. In literature the unknown is published, but he is published only if he is able to impress the editor tremendously. In fact, the unknown must be better than the well-known writer is at best in order to distract the editor's sympathetic attention from even the mediocre and uninspired work of the established writer. So also in science. Established investigators with honors have now as always a prestige which enables them both to gain print and to command respect more readily than mere unknowns. An interesting literature might be cited to prove this, but Murray's "Science and Scientists of the Nineteenth Century" is enough.

Therefore our unknown investigator had to stop and elaborately establish his contention with extreme care. He had to render himself thoroughly familiar with the glutathione literature. He had to match his rudimentary technique against that of experts in this line in order to learn to prepare glutathione. Qualitative tests, three of them, at once demonstrated the baronet's error and supplied valid reason for such a mistake. But in controverting so notable a man only the actual crystallization and identification of glutathione could possibly be admitted as sufficient evidence for publication. So went a year.

At the end of this time of travail the investigator had his theory proven. Not only was glutathione certainly in blood, but it was also apparent that this dipeptide, as such, suddenly left the blood stream to the extent of 40 per cent. dur-

ing one swift passage through the mammary gland. How lightning quick this transference must be we know when we remember that glutathione occurs only in the corpuscles and must transfuse from them into the blood plasma before the mammary cells can grasp it to build into milk proteins. Moreover, the fact that a dipeptide was actually so used as such and without being broken down into its two constituents (the amino acids) afforded the first instance of such a biological utilization and demonstrated that the amino acids are not invariably the only building stones ever used by the organism. This in turn controverted facts established by all noted workers and effectually damned the particular investigation.

Therefore, our unknown investigator, after more than two years of zeal and after finding something entirely different from what he started out to find, was at last ready to risk publication. He could have rushed to print half a dozen times earlier and would have then produced the usual half-baked article.

But now, before his article can appear, the British *Biochemical Journal* arrives, announcing the isolation of glutathione from mammalian blood in the Cambridge laboratory of Sir F. Gowland Hopkins! Hopkins has rectified his error.

Our unknown therefore extracts what acrid satisfaction he can from his empty "confirmation" and tries to laugh. He finds later—so uncorrelated and overlapping is research—that two other investigators were directly on his heels. There they all were inefficiently groping separately, largely because a great and respected man had made a mistake and also because there is no world agency for effectively coordinating research.

So our investigator smokes meditatively, smiles sardonically, gathers up the pieces, investigates, sees where he is and starts afresh on some other corner of that immense problem—"The Mystery of Life." For the moment he is blocked by the fact that even his second valid discovery contravenes all accepted theories and will hence scarcely be accepted if he publishes it. Perhaps some new problem would be more fruitful anyway.

At any rate we see how he spends his time. So he proceeds from day to day. So he gropes and wanders. Of such is the kingdom of research.

INVESTIGATIONS OF LIFE IN THE SEA

By Professor W. E. ALLEN

SCRIPPS INSTITUTION OF OCEANOGRAPHY OF THE UNIVERSITY OF CALIFORNIA

THERE is no evidence that life in the sea is fundamentally or essentially different from life on land. The same laws of origin, distribution, maintenance and destruction are operative in both regions. Those differences in life in the two regions which attract our attention are differences in degree rather than in kind and are incidental to the character of the media in which the organisms are immersed. It is, therefore, reasonable to suppose that investigation of marine life may be, to a considerable extent, guided by knowledge and experience gained through investigation of the more easily accessible land and fresh water life.

The herdsman going into new country estimates its productivity by the vegetation spread before his vision. If his estimate be made from a single view he may be grossly deceived according to his presence in wet or dry season of the year or in wet or dry year of a climatic cycle or in a robust or diseased population of a biological cycle. In the history of our country many fortunes have been made and many have been lost on the basis of such single observations. Successful men are, however, disposed to reserve effort and expense until other views have been obtained. Having established himself in promising territory an intelligent herdsman then begins a series of more detailed studies of the conditions determining its productivity, the water supply, the plant succession, the animal migrations, the prevalence of pests, the indications of overloading and many others. For handling the details of such problems he soon finds himself incompetent through lack of ability, lack of time and lack of mental and physical equipment. He then seeks the aid of specialists who trace individual threads of influence in the fabric of condition and circumstance and who show, here and there, one that is harmful, another that is immediately and constantly valuable and another that is practically negligible. In most cases the success of a specialist in following a thread of influence is dependent upon his ability to forget every other thing and to concentrate his attention upon the ramifications of his particular thread. For that reason utilitarian aims in any biological research must receive scant attention except at the beginning or end of particular investigations, when they may suggest a problem or direct some application of its solution.

On account of the profound difficulty of carrying on investigations in the sea, due to expense, to limitations of space and time, and to obliteration of vision, the things which have just been mentioned are even more impressive than they are in connection with the work on land. The herdsman's single view of a landscape is vastly superior, as a basis of estimate, to a single visit of a fisherman to a locality of similar scope. Hundreds of items within the range of vision in open country contribute to the validity of a conclusion, none of which are available to the man who has little or no information beyond the catch (not the sweep) of his net. As a result the forward looking fisherman is more immediately dependent upon investigations by experts and specialists and the specialists are confronted with the necessity for high frequency and high continuity of

observations, both in space and time. Burdened with such necessities, the marine specialist, even more frequently than the land specialist, may be obliged to postpone consideration of the economic application of his observations until they have attained moment or definition sufficient to indicate so-called "practical results."

In the sea, no less than on the land, synthetic vegetation constitutes the basic link in the chain of sustenance of living things. In tide water, along shore, and on the bottom, algae and diatoms correspond to herbage on land. Floating in the water, diatoms and coccolithophores have such a relationship. Any effective biological survey of a marine region or locality must, therefore, as on the land, be based on a survey of the vegetation of its region, and no estimate of its productivity can have perennial or permanent value unless it includes careful estimates of the normal production of plants and of the annual range of production. Obviously, in consideration of the sharp and narrow limits of observation, the details of such problems can not be solved, or even stated, in terms of small magnitude.

Pending the development of investigations of large magnitude it is both desirable and necessary to make use of fragmentary and incomplete investigations, their application being subject to revision as expansion warrants. For example, it is pretty generally understood amongst marine biologists that certain organisms are so abundant, so widely distributed, so easy to study, and so important as links in the food chain, that they have great practical importance in estimating biological productivity in the sea. Most prominent amongst such organisms are diatoms, representing the plants, and copepods, representing the animals. Fortunately, both groups of organisms are known to have a close relationship to the welfare of fishes. Evidently, a good working knowledge of the numbers and successive shifts in numbers of these organisms in a given area and a record of the changes in kinds will give the best basis for developing an understanding of the conditions of productivity in that area. Records of numbers made from observations of high frequency and continuity resemble meteorological and astronomical records in the fact that their reliability and value increase as they perennially accumulate. Many biological problems which now seem hopelessly intricate may prove soluble after accumulation of records similar to those of astronomy.

On land, the ecological botanist or zoologist marks off a quadrat, selected by ocular inspection as typical of the local population, and in it makes a detailed study of the residents. In the sea this is not possible with the free living forms most favorable for quantitative study, and a fair estimate of the numbers and component forms of the residents can only be reached by a number of catches great enough to represent the whole area being studied. It is seldom possible to procure such numbers of catches and a larger or smaller percentage of error must be expected according to the number and spacing of the catches. Catches made frequently over a period of years or decades give ground for estimating the importance of this error and finally lead to a good general understanding of productivity.

As population increases and the demand for food and other natural products becomes more exacting the assistance of experts in handling marine products is going to be needed to furnish the margin of safety in estimating marine productivity and the trend of good or bad influences on marine life. Consequently, it seems that the laying of the foundation of understanding of marine populations through accurate study of those forms most suitable for use as indicators of productivity and of the influences most prominent in influencing it is immediately important.

THE MONGOLIAN AGE OF MAMMALS

(MONGOLIA THE NEW WORLD, PART IV)

By Professor WILLIAM K. GREGORY
AMERICAN MUSEUM OF NATURAL HISTORY

THE geologists of the Third Asiatic Expedition of the American Museum of Natural History found in the Gobi region two major divisions of rock formations. Very large areas, Messrs. Berkey and Morris state, are covered with younger sediments that lie nearly flat. The strata themselves are simple and wherever they are disturbed the deformation is of comparatively simple type also—either gentle warping or, somewhat more rarely, sharp flexure and actual normal faulting. In all other areas much more complex rock formations are exposed, representing a more ancient floor which is doubtless continuous beneath all the sediments. This was the "Oldrock floor," in which, as we saw (Part I), the geologists found the much folded and metamorphosed remnants of very ancient rock series, often more or less penetrated and cut by granite or other igneous rocks. It will be recalled also that one of the formations in the Oldrock floor consisted of marine beds containing invertebrate fossils like those of the Permian age of China and Europe. Thus one at least of the components of the Oldrock floor could be assigned to its approximate position in the standard "geological column" of successive formations.

The "younger" sediments lying above the Oldrock floor and found in the separate basins of the Gobi region were not marine formations and thus contained no marine invertebrate fossils. How, therefore, could they be correlated with each other and with the standard marine series of Europe? But they did include in all some seven thousand feet of sediments heaped up by the rivers and winds and comprising about a dozen distinct horizons all containing vertebrate fossils. Thus Mongolia, like India, Europe, North America and South America, was found to have its paleontologic column of continental deposits of the Age of Reptiles and of the succeeding Age of Mammals. In all these other countries the paleontologists have sought to determine which horizons in different parts of the world were more or less contemporaneous. By comparing the history or evolution of related families in different parts of the world they have further sought to discover where a given family originated and by what routes it later became dispersed to various regions.

At the bottom of the Mongolian column of vertebrate horizons we find the Oshih (Ashile) formation, containing fossil teeth and vertebrae of a large sauropod dinosaur named *Asiatosaurus* by Professor Osborn and closely related to the huge *Camarasaurus* of Colorado (see Part II). In the same formation was found also the remarkably perfect skeleton of the small beaked bipedal dinosaur named by Professor Osborn *Psittacosaurus* (Part II). The presence of these reptiles has led Professor Osborn to correlate the Oshih formation with the Morrison or Lower Cretaceous of Colorado and Wyoming.

Considerably above this horizon comes the Djadokhta formation, which yielded

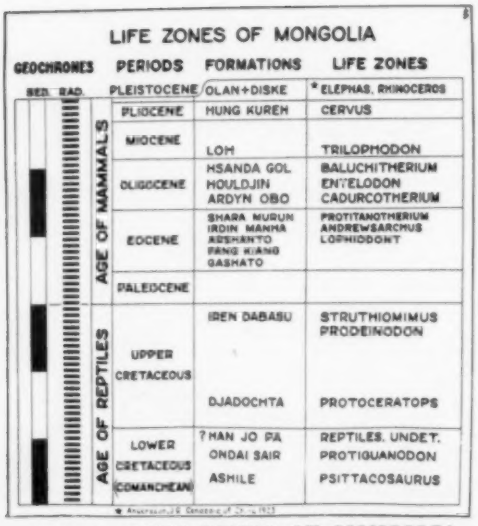


FIG. 1. LIFE ZONES OF MONGOLIA
BY STAFF OF CENTRAL ASIATIC EXPEDITION.

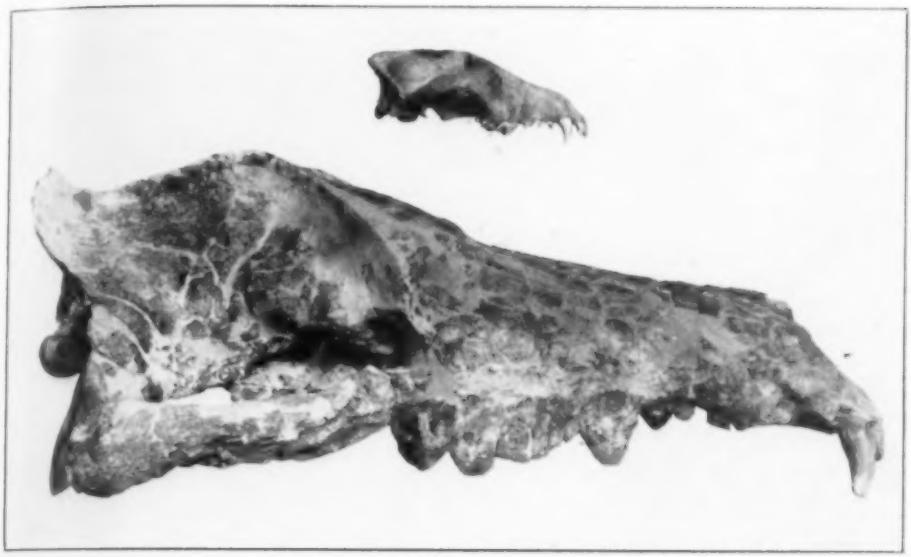
the famous collection of dinosaur eggs and skeletons (*Protoceratops*) and the priceless skulls of small mammals (Part III). These dinosaurs are distinctly smaller and more primitive than their huge relatives, the horned dinosaurs of the Upper Cretaceous of Montana and Alberta, and hence the Djadokhta formation is provisionally placed in the lower levels of the Upper Cretaceous.

The Djadokhta formation was subjected to a long period of erosion, but afterwards there was deposited upon it a series of two hundred feet of reddish and drab sediments to which the name "Gashato formation" has been assigned; this yielded a puzzling fauna of small and primitive mammals described by Dr. Matthew in 1925. Perhaps the most important specimen is a small

Photograph by American Museum of Natural History

FIG. 2. MODEL OF *PROTITANOTHERIUM* HEAD

MADE BY ERWIN S. CHRISTMAN UNDER THE DIRECTION OF WILLIAM K. GREGORY FOR PROFESSOR OSBORN'S MONOGRAPH ON THE TITANOTHERES. BASED ON THE FOSSIL REMAINS OF *Protitanotherium emarginatum* FROM THE UPPER EOCENE OF UTAH, CLOSELY RELATED TO *Protitanotherium mongoliense* OF THE GOBI DESERT.



Photograph by American Museum of Natural History

FIG. 3. *ANDREWSARCHUS* SKULL AND WOLF SKULL FOR COMPARISON

Photograph by American Museum of Natural History

FIG. 4. RESTORATION OF *ANDREWSARCHUS* BY E. R. FULDA

Protitanotherium IS SEEN IN THE DISTANCE.

Photograph by American Museum of Natural History

FIG. 5. RESTORATION OF *BALUCHITHERIUM* BY E. R. TULDA

lower jaw about an inch long, with molar and premolar teeth of a peculiar type which is fundamentally like that of certain extinct mammals of the Deseado formation of Patagonia. Fragments of upper jaws with teeth of the same species also have a distinctly "South American" appearance. Hitherto the only known fossil form of this general type found outside of South America has been a minute lower jaw from the Lower Eocene Wasatch formation of Wyoming, previously described by Matthew. Thus Mongolia, Wyoming and Patagonia seem to be on the dispersal route of these strange little mammals. But in which direction did the dispersal take place?

All the fragments of jaws and teeth found in this formation are peculiar in one way or another, but as a whole they appear to suggest a Basal Eocene (Paleocene) age. They tend also to strengthen Dr. Matthew's view that the stem forms of the whole series of South American orders, which dominated that region for millions of years, might be traced back eventually to still earlier and less specialized ancestral stocks originating in the Northern Hemisphere before the route to South America was cut off.

Above the Gashato formation there follows apparently a considerable break in the record, representing all the great mammalian faunas of Lower and Middle Eocene age in Europe and North America, no trace of which has thus far been found in Mongolia. The history is resumed in the Irdin Manha formation, from the type locality of which a large collection of fossil mammals was obtained. Here were several kinds of small lophiodonts and related hoofed animals that were allied to the tapirs on the one hand and to the rhinoceroses on the other. Many allied forms have been found in formations of Eocene age in

Photograph by American Museum of Natural History

FIG. 6. SKULL OF *BALUCHITHERIUM*

FOUR FEET, TWO INCHES LONG.

FIG. 5. RESTORATION OF *BALUCHITHERIUM* BY E. R. FULDA

Photograph by American Museum of Natural History

FIG. 7. EXHIBITS OF HISANDA TOE AND GALLERY IN THE HALLS

Photograph by American Museum of Natural History

Europe and Western North America but for the most part, at least, these Mongolian forms were not directly ancestral to either their European or their American relatives. The relationship, however, is sufficiently close to establish the fact that there had at some time been some route or pathway between these widely distant regions.

This view is fully confirmed by the presence in this Irdin Manha formation of a great number and variety of titanotheres. This peculiar extinct family of hoofed animals in North America extended from the Lower Eocene through the Middle and Upper Eocene to the close of the Lower Oligocene, during which time the family was represented by nearly two hundred known species, ranging from very small primitive hornless forms in the Lower Eocene up to the gigantic animals with a transverse pair of "horns" above the eyes in the Lower Oligocene. At that time these animals were extremely abundant in what is now the "bad land" region of South Dakota and Nebraska, and their fossil remains were ascribed by the Indians to the legendary "thunder horse." The numerous Mongolian titanotheres of the Irdin Manha and of the succeeding Ardyn Obo formations show the most striking resemblances to the related forms of corresponding horizons in North America. So far no trace of the older Middle and Lower Eocene titanotheres, which are so abundant in the Bridger and Uinta mountain basins of Wyoming and Utah, have been found in Mongolia and in this case the evidence at first suggests that the earlier stages of the family were passed through in western North America, and that the family spread thence to Mongolia, one or two representatives penetrating also to Western Europe.

These peaceful herbivores of the early Mongolian forests and plains were preyed upon by an assortment of carnivores which are plainly related to those of similar age in Europe and North America. Easily the chief of these was the huge *Andrewsarchus*, with a skull thirty-three inches long. Professor Osborn, who described this skull, tells us that "This is the largest terrestrial carnivore which has thus far been discovered in any part of the world. The cranium far surpasses in size that of the Alaskan brown bear (*Ursus gyas*), the largest living carnivore, which, when full-grown, weighs 1,500 lbs.; in length and breadth of skull, *A. mongoliensis* is double *Ursus gyas* and treble the American wolf (*Canis occidentalis*). It is also treble the size of its American relative *Mesonyx obtusidens* from the Middle Eocene of Wyoming and double that of *Mesonyx* (*Harpagolestes*) *uintensis* from the Upper Eocene of northern Utah, Uinta B."

The three-toed horses, so characteristic of North American horizons of equivalent ages (Upper Eocene and Oligocene), were conspicuously absent so far from the Mongolian record, while the paleotheres, numerous in the Eocene of Europe, were likewise unrepresented. As yet no one knows why these families were absent or why the horses apparently did not reach Mongolia until Pliocene times.

The Hsanda Gol formation, also of Oligocene age, contains one of the most extraordinary fossil animals ever discovered, the gigantic rhinoceros *Baluchitherium*. Formerly discovered by an English paleontologist, C. Forster Cooper, in Baluchistan, and found also by the Russians in Turkestan, the American Museum expedition was highly fortunate in securing a nearly complete skull and parts of the skeleton of this amazing animal at Hsanda Gol in the western part of the Gobi region. The skull is

Photograph by American Museum of Natural History

FIG. 8. RECOVERING AND PHOTOGRAPHING A FOSSIL ELK ANTLER

not less than four feet, two inches long and the column-like hind foot measures more than three feet from the heel to the ground. The estimated height at the shoulder is about thirteen feet, higher than the tallest elephants but less massive.

Under the feet of this titanic animal scampered a remarkable profusion of rodents, some related to the queer gopher-like rodent *Bathyergus*, others to the squirrels, dormice, rats and mice and pikas, all of which have been identified and named in papers by Dr. Matthew. Students of the evolution of these teeming groups will find much of interest in the Mongolian fossils.

In the Loh formation, a thin deposit lying above the Hsanda Gol, the long-jawed mastodons arrive, represented by a relative of the European *Mastodon angustidens*. This formation is referred by Professor Osborn to the Lower Miocene. A rhinoceros from this formation has the molar pattern more advanced than that of *Baluchitherium* and appears to be related to one of the true rhinoceroses of the Miocene of Europe (Matthew).

The Hung Kureh formation, succeeding the Loh formation, marks the first appearance of the horse in this region. It also contains deer and ostrich remains and apparently represents the Pliocene epoch.

Later than the Hung Kureh formation is the loess of China (fine wind-blown dust, more or less consolidated). This, with other formations, represents the long period which in Europe and North America witnessed the slow advances and retreats of the great continental ice sheets. The glaciers, however, never invaded Mongolia.

Accordingly, the Mongolian record of the Age of Mammals has thus far brought to light several new and strange forms, as the gigantic carnivore *Andrewsarchus* and the still more gigantic *Baluchitherium*. Apart from such novelties, it shows many striking elements of affinity with the well-known fossil faunas of North America, Europe and India, so that there can be no question that at least at times there was a free land passage between western North America, Mongolia and western Europe. The Mongolian animals may have spread eastward over the Behring Straits route into northwestern North America; by travelling westward they would find their way into western Europe; southward they would soon have reached India and Burma.

Thus it is tempting to look to Mongolia as the Garden of Eden for every one of the higher mammalian families, from mice to men, and to think of every group as originating in Central Asia and dispersing toward the southeast, south and southwest. But very probably the facts are far too complex to fit any such simple explanation. In the case of the titanotheres, for example, the earliest very small and primitive members of the family appear in the Lower Eocene of North America, immigrants from some still unknown region. Professor Osborn, assisted by the writer, has shown that at every known horizon in North America, from the Lower Eocene to the close of the Lower Oligocene, we meet with the more and more modified descendants of the earlier inhabitants of a given region, together with new types that appear to be immigrants from some other quarter. Certain genera of the Upper Eocene titanotheres of both Mongolia and North America (*Dolichorhinus*, *Telmatherium*, *Protitanotherium*) appear to be the direct descendants of earlier titanotheres in the Middle Eocene of North America

Photograph by American Museum of Natural History

FIG. 9. WALTER GRANGER EXCAVATING A FOSSIL RHINOCEROS SKULL, 300 MILES SOUTH OF URGA.

(*Mesatirhinus, Telmatherium cultridens, Manteoceras*). In the case of the titanotheres it appears that the dispersal took place at first in one direction and then in another, and the same appears to the writer to be true of the mesonychid, oxyaenid and hyaenodont carnivores, also of the amblypods, lophiodonts, amynodonts, true rhinoceroses and certain artiodactyl groups.

But what we already know of the Mongolian life record is obviously only the promise of what is to come, if Roy C. Andrews, the Ulysses of paleontology, succeeds in getting his expedition into the field this year.

Photograph by American Museum of Natural History

THE LIFE HISTORY OF THE FISH ASTROSCOPUS (THE "STARGAZER")

By Professor ULRIC DAHLGREN

PRINCETON UNIVERSITY

In the littoral waters of our Atlantic coast lives a fish, commonly called the Stargazer, *Astroscopus*, whose life history, relationships and adaptation to its environment are so remarkable that the writer, who has studied it at intervals for over twenty years, thought the story ought to be told, especially as so few people know the fish or even suspect its remarkable history.

In 1884 attention was first called to the animal by reports that it was capable of giving a rather strong shock of electricity, and an examination of an alcoholic specimen kindly sent from the U. S. National Museum soon showed that an electric organ of a new type was present. The studies that followed brought the writer into such close and intimate contact with this fish that other equally interesting facts were brought out and upon them rests the following account.

The fish belongs to a very large group of fishes, the order Acanthopteri, which is so heterogeneous and large in its composition that this position does not signify much as to the relationships of the stargazer. The more immediate and smaller sub-group to which it belongs is a division of the fish world known as the "Trachinoidea" or "sand fishes." In the several families of this group we find many genera and species which, aside from the more technical features of their internal anatomy, clearly show a blood relationship. They show, more or less plainly, easily observable external features of form, color and structure which go to demonstrate that the major portion of all the genera and species have an inclination to live on a sand bottom and, more specifically, to live very close to the sandy bottom or even *in the sand*. Even further than this, to live in the sand in a *certain way or manner*.

Many other fishes or whole groups of fishes have developed the ability to live in or on the sand, as the little silvery sand eels, *Ammodytes*, which dive into it and burrow through it with their sharp noses and long eel-shaped bodies; or as the flounder tribe, which have turned over on right or left side, developed a protective coloration and a secondary bilateral symmetry and long fins on the two sides (once the dorsal and ventral edges) with which they can glide over the bottom or even, by a peculiar flopping motion, quickly bury themselves completely in the mud or sand. Again, the skates and rays, instead of lying over on one side to take advantage of the natural lateral flatness of a fish's body, as the flounders have, are flattened dorso-ventrally to produce a flat form so that they can act much in the way that the flounders do.

While many of these other general groups have attained a considerable adaptation to living on sandy bottom, and a skill in burying in the sand, these features have reached their climax in *Astroscopus* (Fig. 1) and will now be described in connection with an account of the habits of the fish. It is notable that this fish has attained these adaptive structures without noticeably altering its general "fish-like" form from that found in a sculpin or toad fish.

Astroscopus does not move around

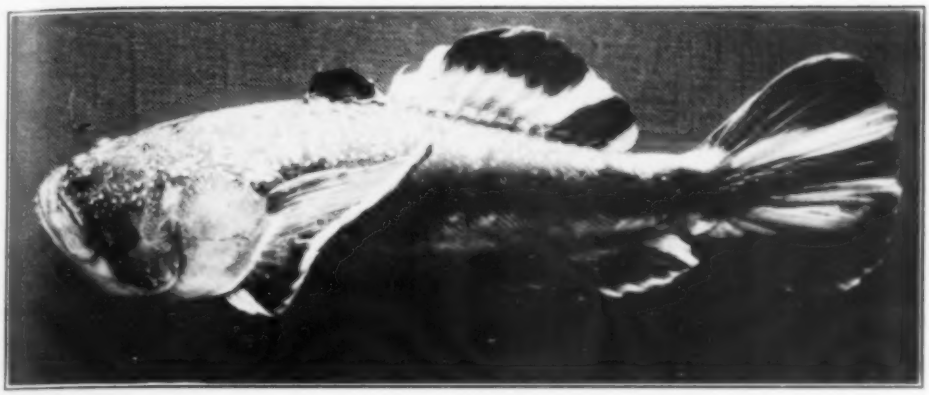


FIG. 1. PHOTOGRAPH OF A SIX-INCH *ASTROSCOPUS GUTTATUS* FROM BEAUFORT, N. C. THE OUTLINES OF THIS SPECIMEN ARE SOMEWHAT MORE ROUNDED THAN THEY WILL BE WHEN SUCH A FISH IS ADULT AND THE FINS ARE PROPORTIONATELY LARGER. NOTE THE CURLED UP EDGE OF THE PECTORAL FIN WHICH IS USED TO LEAD AWAY THE RESPIRATORY WATER FROM THE GILLS WHEN THE FISH IS BURIED IN THE SAND. ALSO THE SPOTS ARE LARGE FOR THE TYPICAL *Astroscopus guttatus*. COMPARE THEM WITH THE SPOTTING OF THE SKIN SEEN IN MORE NORTHERN SPECIMENS (SEE FIG. 5). THE SPOTS ARE ALSO SMALLER THAN THE SPOTS IN A TYPICAL SPECIMEN OF *Astroscopus y-graecum* FROM FURTHER SOUTH (SEE FIG. 11). PHOTOGRAPH BY C. W. SILVESTER FROM A SIX-INCH BAY FISH.

much except when migrating and then swims slowly and clumsily. When he stops he comes to rest, always on sandy bottom and at once begins to squirm with short, side-to-side motions of his ventral surface and tail, holding the caudal and anal fins rigidly so that these fins begin to open up a trench into which the body sinks. At the same time the two large strong pectoral fins and the ventral fins begin to perform an outward shovel-like motion which digs a hole rather than a trench under the heavy forward part of the body.

The animal keeps up this motion while resting on its belly in a horizontal position and in that position it sinks directly downward. This action is guided in its rapidity by circumstances. If undisturbed and not pursued the side-to-side motions are each about a second in duration, the sand is pushed aside and when about two thirds under the surface the animal stops and rests (Fig. 2), resuming in a few moments and carrying the process to a point where only the front tip of the head and possibly the upper tip of the caudal fin are visible (Fig. 3). If frightened and seeking to escape, however, it alters this procedure. It rushes forward and doubles on its path several times, often executing one or two clumsy somersaults near the bottom to stir up the sand and hide its movements, then, suddenly straightening out in a horizontal position, it vibrates and digs as described, so violently and quickly that by the time the sand has settled it has disappeared beneath the surface. It may go down for as much as twelve inches or more. The writer once spent a beautiful October afternoon wading along Buckrow beach near Old Point Comfort, Virginia, in about three feet of water on a clean sand bottom, and, among the other fishes seen, were seven stargazers. All were concealed just under the surface of the sand and when touched with the boot or net handle sprang out of the sand, dashed off about a dozen feet and

went through this performance. Five of these were captured by the bare hand which was pushed down in the sand at the spot where the animal had sunk until the fingers could be closed tightly around the still burrowing fish, now six or more inches below the surface, which was then drawn out and carried ashore. One of them got down fully twelve inches in the loose sand before capture and two were not found, either because too deep or because it had not been possible to properly locate the spot where they sank. One kept in the Washington Aquarium was nearly always half buried in the sand (Fig. 2) or just under the surface with a small patch of the upper head showing. The next photograph (Fig. 3) was taken from above of a living stargazer in the sand at Beaufort, N. C. This fish had been in this same position all day but came out and moved about some in the evening.

The first adaptation to be mentioned, a slight one, is in the general shape of the body, particularly the flattened upper surface of the head, which surface extends out as a plane to the extreme tip of the snout, making the front of the anterior end blunt and enabling the whole body to be just submerged so that mouth, nostrils, eyes and other organs, while almost concealed, are still at the surface.

The second adaptation is the development of caudal, anal, pectoral and ventral fins to a strength and position in which they can do the digging (Fig. 1). The ventral fins also have been moved forward where they will best assist the pectorals in burying the head. In connection with this there are undoubtedly nerve reflexes and coordinating mechanisms established that operate these various motions for their most efficient work.

The third adaptation, that for sight, lies in the anterior position of the eyes and their position on the flat top of the head. Not only this, however, for the eyes can be moved up and down so that they either protrude a short distance to see above the very thin covering of sand or lie flat in their sockets. This appears to be accomplished by the filling of the tissues back of the eye with some body fluid, so that they arise on short stalks for as much as one quarter of an inch. The writer has also seen this eye raising in flounders, skates, gobies and other bottom fish that live on the bottom or bury in sand or mud. It is not present in most fishes.

The fourth adaptation is an extensive and somewhat complicated organization of parts of remarkable interest and is connected with the breathing of water. It must be considered in detail as several

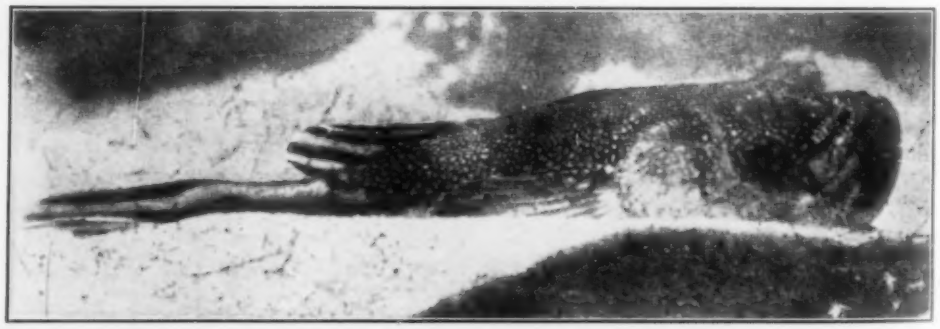


FIG. 2. PHOTOGRAPH OF A LIVING *ASTROSCOPUS GUTTATUS* HALF BURIED IN THE SAND IN THE AQUARIUM IN WASHINGTON. CAPTURED AT NORFOLK, VA., AND SHOWS THE FINE-SPOTTED PATTERN OF THE TYPICAL NORTHERN STRAIN. FROM D. S. JORDAN'S BOOK ON FISHES AFTER A PHOTOGRAPH BY DR. R. W. SHUFELT FROM A TWELVE-INCH BAY FISH.

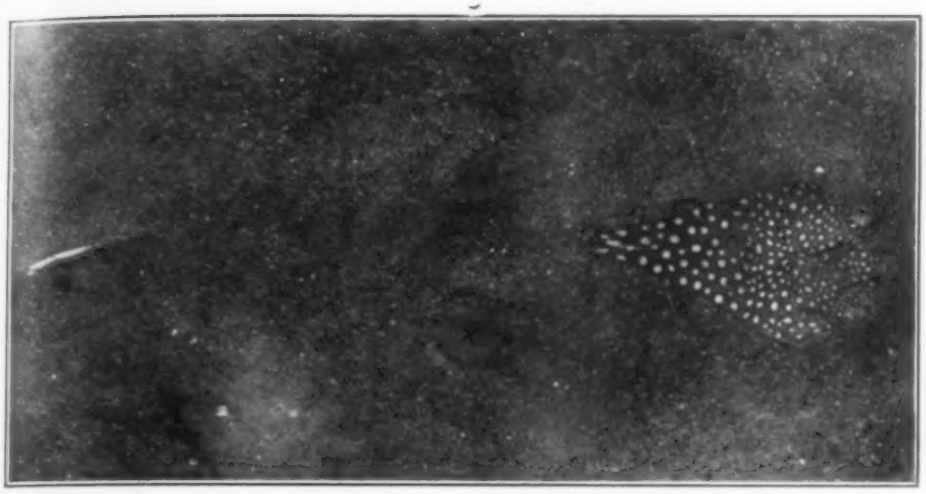


FIG. 3. PHOTOGRAPH OF A LIVING *ASTEOSCOPUS GUTTATUS* BURIED IN THE SAND AT BEAUFORT, N. C. THE TOP OF THE HEAD AND UPPER TIP OF THE TAIL ARE ALONE VISIBLE. HALF WAY BETWEEN HEAD AND TAIL NOTE THE TWO SMOOTH SPOTS (×) ONE ON EACH SIDE, WHERE THE GRAINS OF SAND ARE DANCING IN THE TWO CRATERS THROUGH WHICH THE RESPIRATORY STREAM OF WATER IS PASSING UP FROM THE TIPS OF THE PECTORAL FINS BENEATH. PHOTOGRAPH BY C. W. SILVESTER FROM A SEVEN-INCH BAY FISH.

interrelated items. First, the fish has developed the very unusual structure of a connection between the narial cavity and the pharynx. In all but *Astroscopus* and one or two other forms of fish the narial chamber has no connection with the mouth cavity but opens to the exterior by two small holes on the outer surface of the head, one opening situated at the anterior end of the chamber and provided with an erect flap of integument so placed as to direct the water into the chamber as the fish swims forward, the other usually posterior to this and designed to allow the water to flow out, thus establishing a current through the chamber for testing the odors in the water by the chemo-receptive nerve endings situated therein. In such case no water can pass from the narial cavity into the pharynx and in consequence most fish can not breathe through their noses.

The narial cavity of *Astroscopus* opens on the outside of the head (Fig. 4) by the usual two holes, but in addition it also opens downward into the large pharynx by a passage of considerable size. What, then, is the course of any water currents? In order to explain this we must first describe the act of breathing which is common to all teleost (bony) fish.

In every such fish the large mouth cavity or pharynx opens anteriorly by a wide lateral slit, the mouth, and posteriorly by two symmetrical and vertical slits known as the gill openings. The sides of this cavity are composed of two large, thin and stiff structures of bone, connective tissue and skin known as the opercula, whose posterior edges form the outer edge of the gill slits. These opercula, hinged on their anterior edge, where they are connected with the skull, are provided with powerful muscles which move them synchronously inward and outward, thus alternately enlarging and contracting the capacity of the pharynx.

When the opercula open, water comes in freely at the mouth but is prevented from coming in at the gill slits by two loosely hung valves called the branchiostegeal membranes, which are hung loosely on the opercula.

When the opercula close, water passes freely out of the gill slits while it is prevented from returning through the mouth by two thin, membranous semilunar shaped valves, the mandibular and maxillary valves, which snap into place in the current and keep the water in.

Thus we have a two-valve pump with

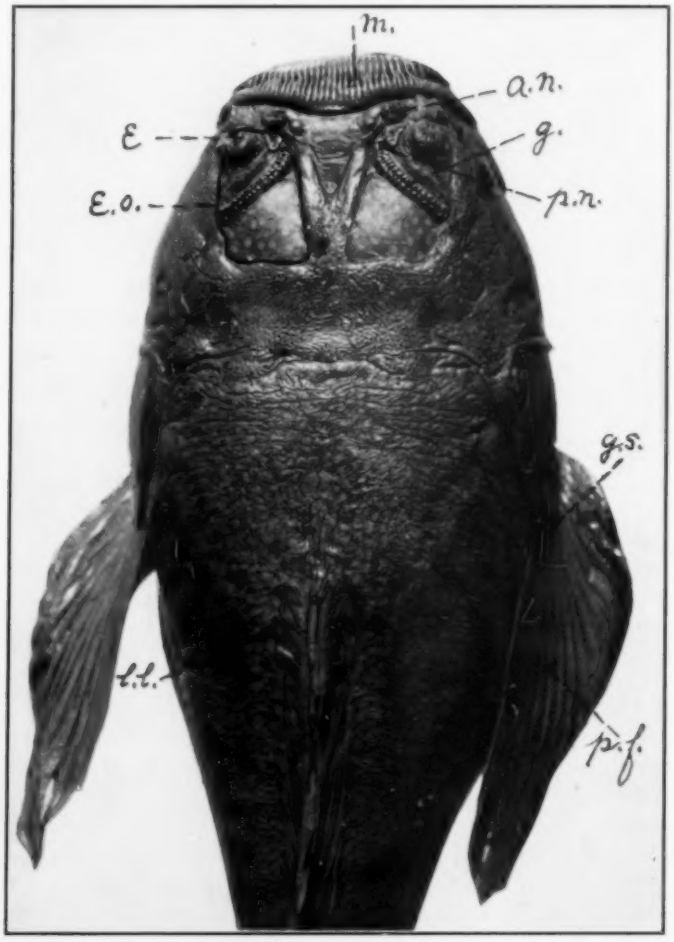


FIG. 4. VIEW FROM ABOVE OF A PRESERVED SPECIMEN OF *ASTROSCOPUS GUTTATUS*

FROM NORFOLK, VA., TO SHOW THE EXTERNAL FEATURES OF ADAPTATION—(E) EYES; (A.N.) ANTERIOR NOSTRILS; (P.N.) POSTERIOR NOSTRILS FROM WHICH THE FILAMENTED GUARDED RESPIRATORY GROOVE (G) EXTENDS BACKWARD AND OUTWARD; (M) MOUTH WITH ITS INTERDIGITATING SIEVE FILAMENTS TO KEEP THE SAND OUT OF THE RESPIRATORY STREAM; (G.S.) GILL SLITS, PROLONGED BACKWARD TO REACH THE BASES OF THE PECTORAL FINS (P.F.) WHOSE OUTER EDGES CURL UP TO PROVIDE A TUBE-LIKE CHANNEL THAT WILL CONDUCT THE EXHALENT RESPIRATORY STREAM TOWARD THE SURFACE OF THE SAND WHEN THE FISH HAS BURIED ITSELF; (E.O.) OUTLINE IN INK TO SHOW THE EXTENT OF THE ELECTRIC ORGAN; (L.L.) LATERAL LINES. A TWELVE-INCH BAY FISH.

the water running backward from mouth to gills in response to the bellows-like action of the opercula and the action of the two pairs of valves. The gills are in this way always supplied with new salt water carrying the oxygen they need for the animals' respiration.

Now we can examine the action of the naso-pharyngeal passage of *Astroscopus* mentioned above. When the opercula expand and water runs in at the mouth in *Astroscopus* it also comes into the pharnyx from the nose through this passage. When the opercula close this water is prevented from running back into the nose by a pair of small membranous valves, one on each pharyngeal end of the two passages. These we must call the two narial breathing valves.

We can now see that the stargazer could breathe through his nose alone, perhaps more slowly but in considerable volume. And he does. The two double nose openings may be free when the mouth is covered by sand.

In the second place *Astroscopus* has still another adaptation in connection with his breathing intended to enable him to breathe when the water is full of flying sand or even when he is buried in loose sand, without having any of this sand drawn into his pharynx. This consists of a row of fine, comb-like serrations on the edge of each jaw, placed so that when the jaws close these fleshy serrations (Fig. 4, m.) interdigitate. A sieve is thus formed that keeps the sand out but lets the water in and, by opening the jaws slightly, he can let in more water when the sand grains are larger, or by closing his jaws further he can keep out the finer grains at the expense of not getting so much water.

The two nose openings on top of the head are also armed with these same, fleshy, comb-shaped fringes. In the case of the small, round, anterior opening this fringe forms a blunt rosette (Fig. 4, a. n.). In the case of the posterior opening (Fig. 4, p. n.) another feature is added. The narial channel, where it comes to the surface of the head, bends over at nearly right angles and forms a long trough or groove whose two upper edges bear a row of the serrations (Fig. 4, g.). In this instance a great deal of water can filter into this groove, more than could flow into a round opening guarded by the serrations and as much as can pass rapidly from the narial cavity down through the naso-pharyngeal tube into the pharynx for respiratory purposes. This modification makes nose breathing a practical feature of the life of *Astroscopus* even when buried in the sand. Many of our own engineering feats in constructing municipal water works are not so well planned.

One more double feature of this fourth adaptation is to be seen in the breathing apparatus of this wonderful fish. This is found in connection with the disposal of the water after it has been used in breathing. The water is not expelled directly into the surrounding sand. We find that the gill slit (Fig. 4, g. s.) is narrowed and drawn backward and upward into a short, loose, baggy tube. This carries the waste water a short way through the surrounding sand. This tube ends near or next to where the great pectoral fin begins (Fig. 4, p. f.). Now the pectoral fin is the most powerful digging machine that the fish possesses, but when the digging is completed the fin remains with its distal end cocked up so that the tip is above the level of the back and the outer fin edge is thin and soft. This edge is curled over into a rounded, closed or partly closed tube (Fig. 1), and this tube communicates with the gill tube so that the waste water is carried still further up through the sand in this channel and discharged from the tip of the fin. In the figure one can see, directly over the tips of the two pectoral fins, two tiny craters in the sand (see Fig. 3, x.). At the bottom of each

FIG. 5. A PRESERVED SPECIMEN OF *ASTROSCOPUS GUTTATUS* (NORTHERN, FINE-SPOTTED TYPE FROM NORFOLK), SHOWING THE ELECTRIC ORGAN DISSECTED OUT ON THE RIGHT SIDE AND WITH THIS ELECTRIC ORGAN DISSECTED AWAY TO SHOW EYE MUSCLES, NERVES AND BLOOD VESSELS OF THE REGION ON THE LEFT SIDE. BOTH EYES IN POSITION. PHOTOGRAPH BY C. W. SILVESTER FROM A FISH ELEVEN INCHES LONG.

crater, over a live fish, a close examination will show the sand grains dancing up and down continuously as they do in the sandy bottom of many springs where the water is welling up.

The fifth adaptation consists of a decided change in the position of the lateral line. The lateral line of bony fishes is an open groove or more often a closed groove or tunnel (Fig. 4, l. l.) opened to the exterior by a series of holes or tubes placed in various symmetrical positions. In this groove or tunnel are sense organs of some unknown function. Various functions have been argued from the perception of sound to the reception of chemical stimuli. This latter may be true.

Whatever this sense may be, it is clear that in a fish that lives buried so long in

the sand, it would be of advantage to have this organ nearest to the surface of the sandy bottom in which it lies buried. In most fish the line pursues a straight direction or gentle curve on each side of the body, often with a sharper upward detour in its anterior end. In *Astroscopus* the lateral lines, beginning well up on the gill opening on each side, run upward at a sharp angle until the two lines lie almost together, one on each side of the dorsal fin or, where there are no fins, on each side of the median dorsal line (see Fig. 4, l. l.). This brings them into a position where they are nearest to the open water and on a part of the body that is last buried when the fish goes into the sand. In fact, most of the fish's time is spent with the top of the head and median dorsal line just level with the sand so that the lateral line is near enough to the surface to operate. This is clearly an adaptation to its habits.

The sixth and last adaptation to the fish's life in the sand is probably a more radical and deeper seated one than any of the others. This is the ocular electric organ which gives off from the eyes and their neighborhood a shock of painful intensity.

In Fig. 4 one can see two rounded oblong areas of considerable size just behind the two eyes. An ink line indicates the limits of one of them. If the skin be removed from the head (Fig. 5) these areas will be seen to represent two wide deep wells in the skull, which pass downward with the same diameter until they open into the mouth cavity, but shut off from communication with this by the skin of the roof of the mouth. In life each well is filled with a mass of grayish, semi-transparent tissue which is the source of the electric discharge.

On microscopic examination of a vertical section of the electric tissue it can be seen that each of these electric organs is composed of about two hundred layers (Fig. 6) of evenly spaced horizontal layers (in a horizontal section it can not be observed) and that each of these layers is constituted by about twenty smaller plates lying side by side (Fig. 7) and of somewhat irregular shape and size, all moulded together to form the regular shape and size of the larger unit which has been called the *electric layer*, while the smaller units of which its lateral extent is composed may be designated the *electroplaxes*.

All electroplaxes have a smooth upper surface and a papilla studded lower surface. These papillae are for the purposes of affording a greater surface for

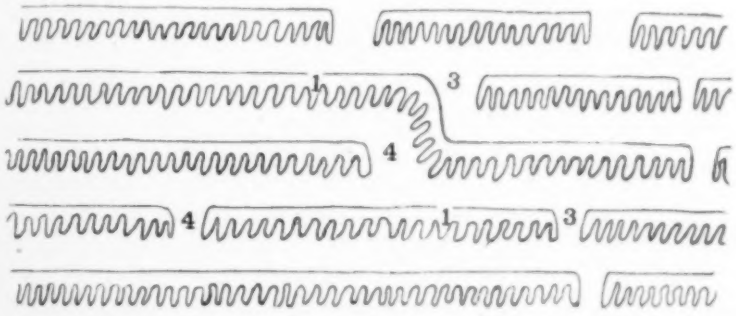


FIG. 6. DIAGRAMMATIC VIEW OF PART OF A VERTICAL SECTION OF THE ELECTRIC TISSUE OF *ASTROSCOPUS*

TO SHOW THE ALIGNMENT OF THE HORIZONTAL ELECTRIC LAYERS. THERE ARE ABOUT TWO HUNDRED LAYERS IN EACH ORGAN IN A FISH AT ALL STAGES OF ITS GROWTH.

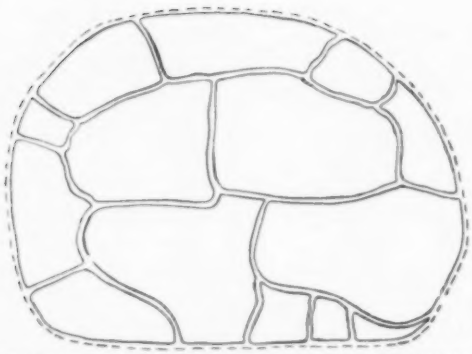


FIG. 7. DIAGRAMMATIC VIEW OF THE TOP OF ONE ELECTRIC LAYER OF *ASTROSCOPUS*

TO SHOW ITS CONSTITUENT ELECTROPLAXES.

exchanges with the blood vessels that are in contact with them and this lower surface may be spoken of as the nutritive surface. The smooth upper surface is studded with thousands of nerve endings formed by the branching ends of a few nerve fibers that come in between each pair of electric layers. The substance of each layer (and its constituent electroplaxes) is striated much as muscle substance is, only the striations are not straight and parallel as in muscle but curved and parallel. We shall see later, as is known about some of the other electric fishes, that each electroplax represents a single muscle fiber. Some of the other electric fishes, as *Electrophorus*, the electric eel, and *Mormyrus*, form each electroplax from several muscle cells instead of from one.

The upper surface of this entire organ represents the negative pole of a source of E. M. F. and the lower surface represents the positive pole. Consequently lines indicating the field of discharge and current during the shock would run from upper minus surface to lower plus surface or down through the organ and from plus around to minus or up outside the organ.

The organ is supplied by fibers from the third or oculomotor nerve whose motor centers in the brain show the usual very large nerve cells found in connection with all electric organs.

One remarkable and puzzling arrangement in connection with the apparatus is the position of the eye and the arrangement of its six muscles and the optic nerve with reference to the mass of electric tissue. The six muscles and the optic nerve reach into the eye socket or electric chamber from the lower and posterior edge of the organ and the eye is over the upper anterior edge (Fig. 5). In order to reach the eyeball they must and do pass for long distances through and around this bulky mass of tissue. What morphological significance has this electric tissue?

First, we know that most electric tissue originates from muscle, and the only muscles in such a locality in *Astroscopus* that could easily form it are the eye muscles. We also know that the third or ocular motor nerve supplies motor stimulus to only certain of the eye muscles and we see here that the electric tissue is supplied with a large branch of this nerve. Both these facts point strongly to one or more of the eye muscles as the source of the electric organ and yet all eye muscles are present, apparently perfect, and are innervated by their proper nerves, the third, fourth and sixth cranial nerves.

Secondly, when first studied, it seemed that this organ might have been developed in early embryonic life from one of the group of three palatine muscles which lay almost next to it, particularly the levator arcus palatini, or from the adductors mandibulae which touched it at another point. This supposition, however, seemed not quite so probable as the eye muscle theory on account of certain arrange-

ments of nerves and arteries which supplied both these muscles and the electric organ.

The best logical supposition that could be entertained, therefore, seemed to be that the electric organ was derived by an unusual modification of a portion of one or more of these eye muscles and since the electric organ was innervated by branches of the third nerve exclusively it was surmised that the muscles involved were one or more of those served by the third nerve, namely, the inferior oblique, internal rectus, superior rectus and inferior rectus. It was not considered that the superior oblique or external rectus could have been involved because they are always supplied in *all* vertebrates by the fourth and sixth cranial nerves, respectively, and these nerves showed no signs of being involved with the electric tissue.

This puzzle could only be solved in one way, it became very evident, and that was by a study of the embryological history of the parts involved. To do this it was necessary to have certain stages of the development of *Astroscopus*, and no one had ever seen a young *Astroscopus*. Nor did any questions addressed to the U. S. Fish Commission, to native fishermen and to others who had observed the fish throw any light whatever on its breeding habits.

The writer determined to get this knowledge and the whole story of how he finally succeeded makes such a typical account of the methods that must often be employed in biological work that it will be related here.

Up to this time the fish had been secured in the summer and fall from trap nets or pounds in the lower part of Chesapeake Bay, only about two dozen in all. Such fish were fairly large, from eight to twelve inches or more in length and were considered fully adult. It seemed a very easy matter to dissect some of these fish and to get considerable information from a microscopic examination of their ovaries in order to tell something about when they bred and, possibly, how they deposited their eggs and even where the eggs were laid.

It may be said here that teleost fish in general have two types of breeding. The first is to throw out into the water a vast number of very small eggs, sometimes several million in number, which are transparent in color and which would sink to the bottom were it not for the fact that many of them possess in their mass one or more globules of oil which, by virtue of the low specific gravity of oil or of the egg itself, cause the whole egg to rise to the surface where development takes place and the young fish hatches and then, after a short larval life on or near the surface of the sea, descends to the bottom, if its parents are bottom-living fish, and spends the rest of its life there. In size such eggs are seldom over two millimeters in diameter, usually much less, and the young fish as well as the egg are both transparent, since probably only such could escape their enemies in sufficient numbers to keep up the numbers of their kind. This is called the *pelagic method* of breeding, since it usually takes place far enough out at sea to prevent too many of the eggs from drifting ashore before they hatch. It is a dangerous method, and vast numbers of the eggs and larval young are lost by being eaten by such fish as mackerel and menhaden, which systematically sift the surface waters through their net-like gill rakers to get them. So the eggs *must* be small and transparent in order that they may be sufficiently numerous and inconspicuous for enough to survive. Many bottom-living fish breed by the pelagic method, as flounders, gurnards, cod, etc.

The other part of the fish world lays its eggs on the bottom either at random or in some sort of nest where they may be carefully guarded, sometimes

even in the mouth, and in all these cases the eggs are usually less numerous, opaque and of larger size. Those laid in nests are often very large and the newly hatched fish are much better able to take care of themselves when they leave the nest than are those that breed by the pelagic method.

It was assumed that *Astroscopus* would be a nest breeder of some kind simply because several of its near relatives, as the toad fish (*Opsanus*) and the midshipman (*Porichthys*) and some others, all lay a very few very large eggs in nests under stones and carefully protect their young until of considerable size.

But when these ten or twelve inch stargazers caught in the summer from lower Chesapeake Bay were examined microscopically under the high-powered lenses as to their ovaries, it was found that all the eggs were so small and so immature that nothing at all could be decided as to their breeding habits.

Such fish were then examined when caught during the time from April to November with the same result, and it seemed that the warmer months were not the months when they bred as most of our Atlantic shore fishes do. It seemed probable that they must breed in the winter months.

So for several years expeditions were undertaken from December to March and the fish were sought in their usual haunts but none was captured. They were dredged for in the shifting sands of half-moon shoals and even in the bay mud where eels and the blue crabs bury and spend the winter, but none were found. The only information obtained was that late in the fall young *Astroscopus* from two and one half to four inches long appeared sometimes in the bay in small schools of several dozen but that even these disappeared in the winter. Did they and the large fish we had been getting dig so deep in sand or mud that we could not reach them or (a new idea) did they go out to sea?

The writer then learned that some fishermen had set several pound nets on the outer shore of the coast at Virginia beach and that one of these nets was several miles out from shore. He visited their fishing camp and after talking with them left some large cans full of preserving fluids (alcohol and formalin) with the promise of reward if stargazers were secured.

The next step to success was secured in this way. In latter May these fishermen found in their traps far larger *Astroscopus* than the writer had ever seen before, weighing fifteen or twenty pounds and measuring as much as twenty-two inches in length, and, best of all, upon dissection it was found that the ovaries were bursting with fully matured and ripe eggs ready to be laid. The eggs were small and transparent and possessed oil globules and it was certain that this fish bred by the pelagic method and that they bred in late spring and early summer. It was also realized that the ten or twelve inch fish in the bay were as yet sexually immature, a very unusual condition, as most fish breed when comparatively young and small.

So the next step was to find the young fish and eggs on the surface of the sea and study the development of their electric organ. The aid of the fisheries experts of the U. S. Fish Commission was sought and one of them brought in, preserved, and sent to Princeton five of the first larval *Astroscopus* that the writer had seen. They were but recently hatched, about four millimeters long and at a stage of development when most pelagic breeding fish leave the surface and go to the bottom if their parents live there as *Astroscopus* does.

Sections were cut and the larval heads were reconstructed in wax and studied

and the disappointment endured of finding that they possessed no electric organ at all or hardly a trace of one. All the eye muscles were present in their proper places and innervated by the nerves that commonly innervate them in fishes and other vertebrates. It even was doubted if these were *Astroscopus* larvae at all but possibly were the young of some other near relative of this fish, as *Kathetostoma*. The muscle fibers in the edges of several eye muscles stained a little darker in color than in others, but this hardly seemed to mean the development of an electric organ.

In August of the next year the Fish Commission steamer *Fish Hawk* was surface towing again some twenty miles off the coast and farther south when her naturalist, Dr. W. W. Welsh, found in the tow and sent to the writer some more larvae of *Astroscopus* of larger size, one of which was nine and one half millimeters long and another fourteen millimeters in length. These were likewise studied, and at last some first trace of the origin of the electric organ was discovered.

The upper edges of the four uppermost eye muscles were seen to be slightly enlarged and to stain somewhat differently from the regular muscle substance. The hypertrophied muscle fibers on the edges of the muscles showed a shortening and widening of one end, another evidence that they *might be* turning into electroplaxes. One still puzzling circumstance was that the superior oblique and external rectus eye muscles were still supplied with nerve fibers by the fourth and sixth nerves exclusively, while the adult electric organ was known to be supplied only by the third nerve. How, then, could we state that the muscle tissues of these two eye muscles played any part in the formation of the matured electric organ? Only an examination of an older stage of the development could show.

Study was then made of some means for securing that older stage, and the writer went to the fisheries laboratory at Beaufort, N. C., to spend the summer and try to get this material. In the first place he now knew that the young *Astroscopus* live on the surface for a

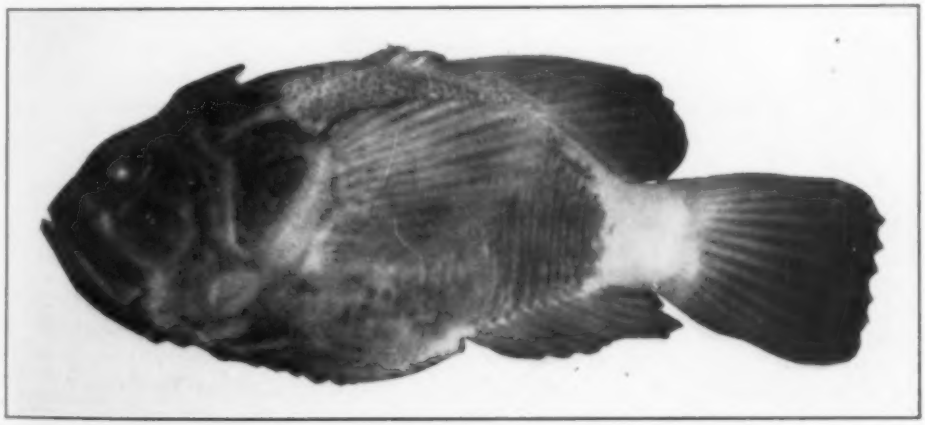


FIG. 8. PHOTOGRAPH OF A PRESERVED TWENTY-MILLIMETER LARVA OF *ASTROSCOPUS*

TAKEN ON THE SURFACE WITH A TOW NET BY THE U. S. F. C. STEAMER *Fish Hawk*, ABOUT FIFTY MILES OFF THE VIRGINIA CAPES.

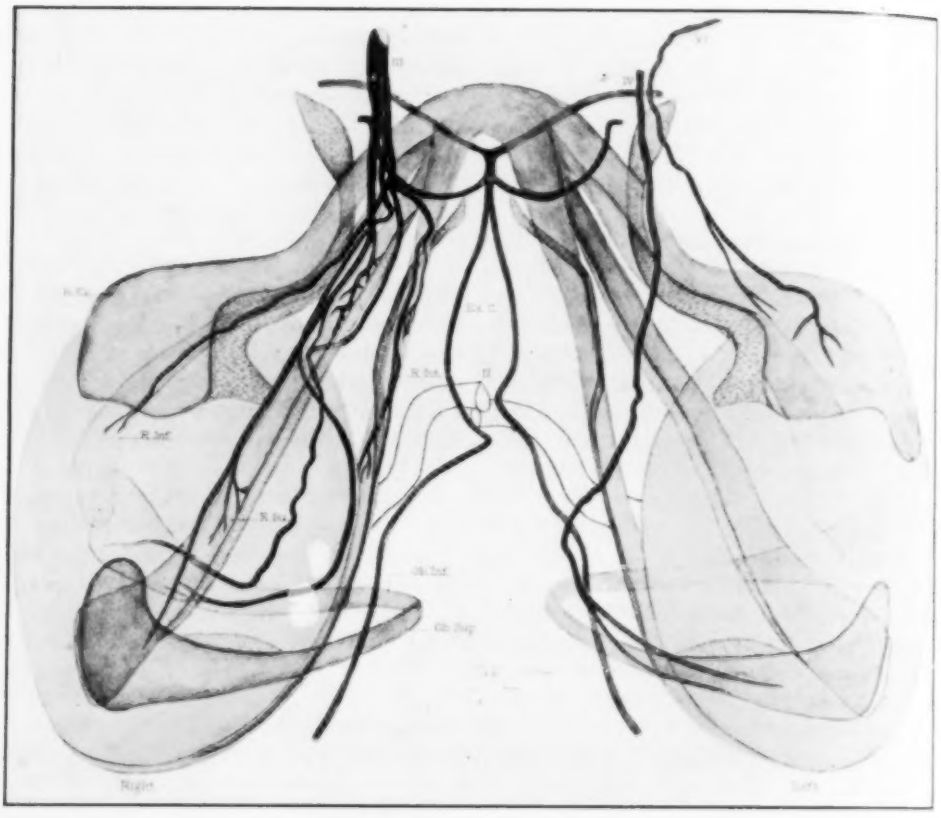


FIG. 9. THE EYES OF *ASTROSCOPUS*

DRAWING OF THE EYES, THE SIX EYE MUSCLES, THE FOUR PORTIONS OF EACH ELECTRIC ORGAN AND THE ASSOCIATED NERVES AND BLOOD VESSELS OF A TWENTY-MILLIMETER *Astroscopus*. THE NUMBERS INDICATE THE NERVES SHOWN, THE INITIALS THE SIX EYE MUSCLES. ONLY THE FOURTH AND SIXTH NERVES ARE SHOWN ON THE LEFT SIDE, AND ONLY THE THIRD NERVE WITH ITS BRANCHES ON THE RIGHT SIDE. THE FEW BLOOD VESSELS SHOWN ARE NOT MARKED. EYE MUSCLES ARE COLORED A SMOOTH GREY TONE, ELECTRIC ORGAN RUDIMENTS ARE STIPPLED. DRAWN BY MISS GRACE WHITE.

much longer time and until a much more complete stage of development than the large majority of pelagic breeders of the fish tribe. This is not so remarkable, as it was known that the file fish, the lump fish, and several others remain at the surface until over an inch or two long, after which they live near the bottom, while some of the flounders, typical bottom fish and pelagic breeders remain at the surface until nearly three fourths of an inch long, so it was possible that *Astroscopus* attains his full development as to electric organ while still on the surface.

The point was, how to get some stages of larval *Astroscopus* larger than fifteen mm. A great deal of towing did not seem to find them. The idea was conceived that the young fish of fortunate

size might be captured on their way down to the bottom by deep towing, but that method failed; so the apparently desperate method was conceived of examining the stomach contents of some kind of voracious fish that lives near but not on the bottom and at once the sea bass, *Serranus*, was thought of. These fish, averaging about two pounds in weight, live in immense numbers near the bottom on some banks a few miles off shore. They are constantly on the alert and hungry for all small diving creatures and it was decided to systematically examine their stomach contents for a considerable period in the hope of getting the desired stage of *Astroscopus*.

This decision was taken the more readily since it was known that many small fishing vessels make a business of catching sea bass in large numbers and dressing them for the market on the grounds. The writer shipped on the cruises of several of these vessels and also went on one trip on the U. S. F. C. *Fish Hawk* off the Carolina coast, and found the fishermen very glad to have some one along who would dress fish for them as fast as caught, although they had grave suspicion of the practicability of his methods or the usefulness of his purpose, even when fully explained.

On a somewhat rough estimate the stomachs of between twenty-five hundred and three thousand sea bass were opened and examined before the first *Astroscopus* was found, and only two were found in all. But these two small fish, one of nearly one inch in length and the other slightly over an inch, were the critical stages sought and told the whole story; especially as Mr. Welsh also contributed another specimen of a little less than one inch (twenty millimeters, Fig. 8) in length, which he had caught in the tow at the surface. The two specimens taken from the sea bass stomach were in an excellent state of preservation for sectioning and histological study, for the first stages of digestion, hopeless as they may appear on first sight, constitute an excellent fixation for the tissues for histological study, and the staining reactions of such tissues are good.

The whole lot of material was turned over to a pupil of the writer, Miss Grace White, who wrote her thesis for the doctor's degree and published the work in the Carnegie Institution Series. Her findings in brief are as follows.

The young *Astroscopus* develops as any other pelagic fish would, while living at the surface of the sea, until over twelve millimeters long. At this time the upper edges of the four uppermost eye muscles begin to thicken and at about twenty millimeters in length these thickened edges begin to separate from the muscle and mass themselves into a group that later constitutes the electric organ (Fig. 9). Those portions that come from the rectus externus and superior oblique eye muscles lose their connections with the sixth and fourth nerves, and branches of the third nerve, which already innervates the other two electric elements, grow out and supply them. Meanwhile all the muscle fibers in all four detached elements of the future electric organ grow shorter and wider until they form flat plates, the electroplaxes.

The electroplaxes have meanwhile grouped themselves into horizontal layers, about twenty in each layer, the layers all lying horizontal in the mass and most accurately spaced apart, with the electric surface up and the papillated nutritive surface down, so that the electromotive force produced by such is added to that of its upper and lower neighbors, in this way producing the sum of about fifty volts during the synchronous discharge of the elements.

Thus we find this remarkable adaptation to sand life, an electric organ on the

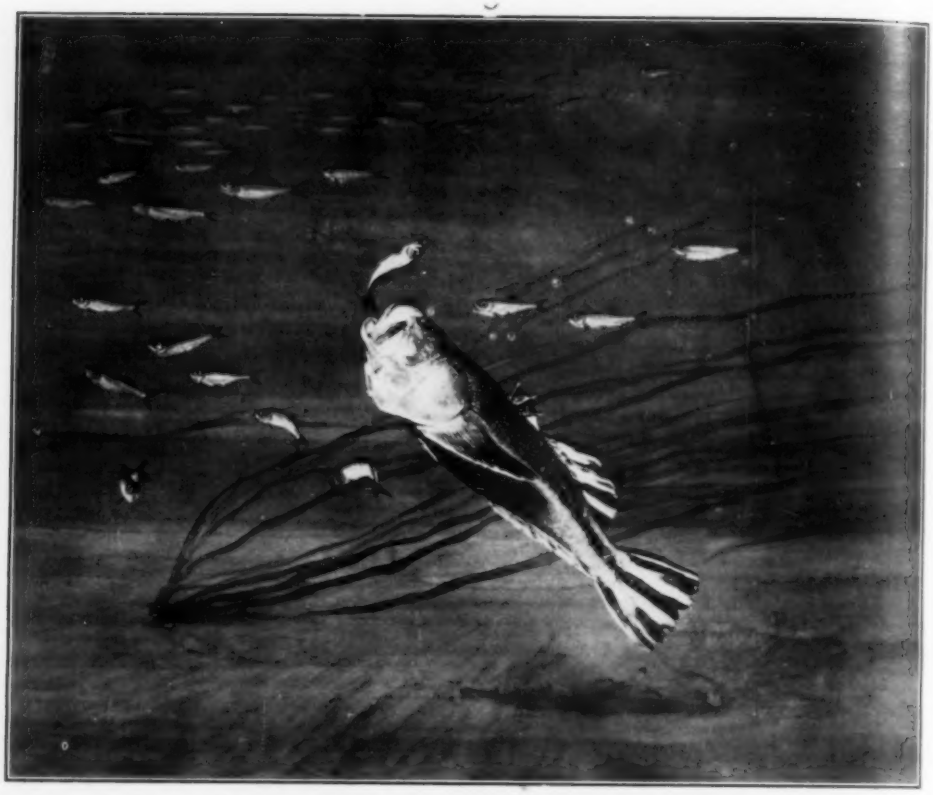


FIG. 10. AN *ASTROSCOPUS* RISING FROM ITS HIDING PLACE IN THE SAND TO CAPTURE A SMALL FISH. DRAWN BY R. BRUCE HORSFALL FROM DESCRIPTIONS BY THE WRITER.

top of the head where it is ready to be discharged when any other creature threatens it from above as it lies buried in the sand. It is also possible that it sometimes uses the organ to stun its prey, which consists of small fish that swim over its hiding place, as is done by the larger electric torpedo with his stronger electric organ. It has no need for this, however, as *Astroscopus* can spring from his hiding place and, rising swiftly, capture such fish, as the writer has seen him to both in the aquarium and in nature (see Fig. 10).

We are now in a position to outline the fish's life history in some of its major aspects.

Its egg is laid in late spring and early summer off our sandy coast in water from thirty to possibly two hundred feet in depth. The egg rises slowly to the surface where it floats and hatches into a little transparent fish only a few millimeters long. It grows rapidly, living on its yolk sac, and when about six or seven millimeters long it begins to eat other and younger fish larvae, very often other *Astroscopus*. It then acquires a black color, which deepens with time, and, later, a bright yellow spot appears on its blunt chin. When about twelve or fifteen millimeters long and probably a month old the remarkable change in its eye muscles begins that results in

an electric organ. At about one inch in length, or a trifle over, it begins to swim deeper and finally swims straight down to find the home it instinctively craves, in the sand. I have often thought of the dangers of this final dive. If it reaches a fine sandy bottom, well and good, but if it comes down on a rocky reef there must be many enemies waiting to receive and eat it. And what happens if it settles on a soft mud? The adult fish dislike mud and avoid it.

The young fish when it settles is a perfect young stargazer in form, with its electric organ almost completely developed and its skin much darker in color than the adult. It is now about two to two and one half months old, and its tendency is to work inshore and seek the mouths of our sandy bays, from Long Island to Florida and the Gulf of Mexico. Great South Bay, Barnegat Bay, Delaware Bay, the Carolina sounds are the places that it likes and it shows

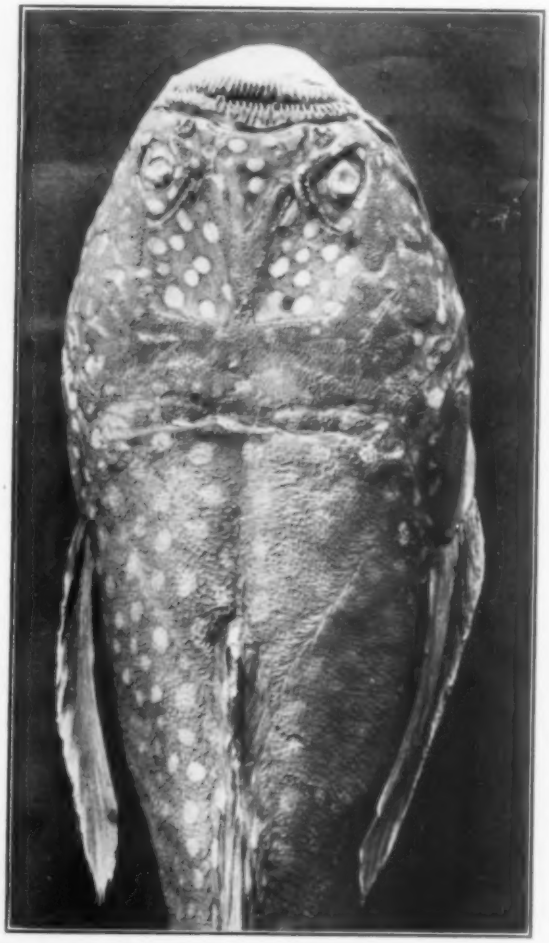


FIG. 11. TOP VIEW OF MOST OF A LARGE SPOTTED *ASTROSCOPUS Y-GRAECUM* FROM GEORGIA, FOURTEEN INCHES LONG. PHOTOGRAPHED FROM A PRESERVED SPECIMEN.

at this age an apparent desire to travel in small schools. When winter comes it probably moves off shore to avoid the severe cold and moves into the bays again the next spring and summer. We have little or no information on this point and in its southern range such short migration is not necessary.

When about eight inches long the fish spends its summers around the mouths of the bays and in their lower wider reaches of water, always staying on the sand and usually bedding in the sand by day and moving about by night. It is also found near shore on the open sandy coast. In the fall, at least in our northern states, it collects at the mouths of the bays and is especially active as cool weather comes on and may often be seen or caught up near the beaches in only a few inches of water. Then, after some cold northwest wind, it is seen no more until spring. We do not know, but it is very probable indeed that it moves off into deep water for the winter. This life, which may be called its bay life, lasts for several years until the fish becomes over twelve or thirteen inches in length and probably from four to six years old. Then it is never seen in the bays again but moves to the sand bottoms some distance off the coast, where it lives permanently, possibly migrating further out in winter and inshore in summer. Now for the first time the ovaries and spermaries, which up to this time have been unproductive in spite of the fish's comparatively large size, mature a crop of ripe eggs and sperm in the early spring of each year, and the fish breed around May or June in the latitude of Norfolk, Virginia. In Florida they breed in January.

Three species of this genus are recorded in the books on fish taxonomy: *Astroscopus guttatus*, found from Long Island, N. Y., to Cape Hatteras, Va.; *Astroscopus Y-graecum* (Fig. 11), found from Hatteras south into Florida and the Gulf of Mexico; and *Astroscopus zepherus*, found on the Pacific shores of the Isthmus of Panama up into the Gulf of California.

In structure all three species are so much alike that very close study is necessary to distinguish between them. This is particularly true of the two Atlantic species. Where they overlap in the neighborhood of Cape Hatteras it seems practically certain that they interbreed, and great variation is found. A prominent external feature of *guttatus* is the large number of white spots set closely together. In *Y-graecum* the spots are larger and less numerous, the size of these marks increasing the further south it lives. Just north of Hatteras many individuals were found in which the spotting characters of the skin conflicted with some of the structural features.

The genus *Kathetostoma* of the same family represents a type from which *Astroscopus* as well as some others of the family *Uranoscopidae* undoubtedly are descended. *Kathetostoma* is much like the young of *Astroscopus* in that while it has the same form and even the spotted back, it has longer spines projecting from the posterior angles of its head, a primitive character according to Dr. D. S. Jordan and other systematists. The species of this genus are found in deeper water in many warm seas.

The family *Uranoscopidae*, of which *Astroscopus* is a member, consists of eight genera and twenty-five species. Most of them resemble *Astroscopus* strongly in general appearance, and *Uranoscopus scaber* from the Mediterranean Sea looks so much like it that it can safely be used as a sample and shown to fishermen when making inquiries as to *Astroscopus*. All twenty-five of these species are found in warm waters with few exceptions and all prefer the sand and show an adaptation to

it. No other genus, however, as far as we know, has gone to the length of developing an electric organ as far as the writer has been able to examine them.

In the next, and a closely allied family, the *Batrachoididae*, we find fishes some of which also closely resemble the unusual form of *Astroscopus*, as the genus *Porichthys* and the genus *Opsanus*. *Porichthys* has also made much progress in the direction of high and unusual specialization in an entirely different direction, however. It has developed a multitude of tiny light-producing organs on its ventral surface. This is not so unusual, however, as the electric organ, since over five hundred other species of fish and many hundreds of other animals in all the animal phyla have done the same.

The above is a brief account of the history of one very interesting fish. Many gaps, some not noticeable to the reader and some not known to the writer, still exist in the account. Thousands of other form have histories that will well repay, in interest and in usefulness, careful study and observation, to the naturalist as well as to the more casual observer. Many have been thus studied. Let us hope that some of these studies will be made complete.

CHEMICAL MICROSCOPY—TIME AND LABOR SAVER

By Professor E. M. CHAMOT

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THE slogan of the day—"Bigger and Better Business"—is finding an echo in shops and laboratories where it is being paraphrased into—"Quicker and Better Service." As a result, fewer useless routine tests and analyses are being made, less valuable time is wasted and more easily interpretable data are being obtained and submitted for consideration and study. This does not mean that fewer tests and analyses are called for, far from it, but it does mean that the technician is exercising better judgment in his efforts to throw light upon some definite phase of a given problem.

It has thus come about that there are few chemists to-day who accept a sample for analysis without further information than "analyze this for me and let me have the results as soon as possible." Before he begins his work, he asks, "Why is an analysis wanted? Just what do you wish to learn concerning this substance, and what reasons have you for believing that it is a chemical analysis that will throw light upon or solve your problem?" These questions arise whether the chemist is a public analyst or whether he is one of the technical staff of a large corporation: in the latter case is it especially true.

The cost of reagents, apparatus and instruments has markedly advanced in recent years; while time and labor have greatly increased in value, at least as measured in terms of speed and in dollars. Furthermore, the "overhead" in all laboratories has reached figures which necessitate a reduction of as much as possible of useless routine analyses.

Here is where the intelligent and judicious use of the microscope has come into play—chemical microscopy—an art which to-day enables the analyst to solve a large proportion of his problems, with a minimum expenditure of energy, time and material. Thus it follows that the returns on the capital invested in this type of laboratory equipment may prove to be relatively much greater than that invested in what we may call the customary equipment of the laboratory.

The purpose of this article is to endeavor to make these points clear and to convince the skeptical that microscopic methods are becoming well established in the chemists' laboratories and that although their advantages were long overlooked their use has become widespread and their value fully recognized.

Microscopic examinations are not being adopted for the purpose of displacing standard chemical analyses but for supplementing them or because information may often be thus obtained which renders chemical analyses superfluous. The following case may be cited as a typical example. An archeologist brought to a chemist the beautiful coin shown in Fig. 1. "Here is an exceptionally fine Greek tetradrachm that has been offered to a collector at a remarkably low price. He brought it to me to have me pass upon its genuineness. I suspect it to be a very clever forgery. It has not the normal weight of a tetradrachm nor does it feel quite right. Take a 'streak-sample' and make a micro-chemical analysis and see whether it is silver or not." "Suppose we look at the coin first under the microscope,"

answered the chemist. "Perhaps it may not be necessary to have recourse to an analysis." Suiting the action to the word, he took one glance; then, turning to his friend, exclaimed, "You are quite right in your suspicion; the coin is spurious. Look, you can see for yourself that the coin has been cast, not struck, for the surface shows well-formed dentritic crystals, with no evidence of having been 'worked,' as would be the case had the coin been struck [see Fig. 2]. Moreover, the crystallization is such as to preclude its being silver, for silver does not give dendrites with this habit. There is little doubt that we have here a base-metal alloy, probably one in which tin predominates."

Thus by a simple microscopic examination the chemist was able to solve the problem put to him by the archeologist. It required only a few minutes, affected the coin in no way and required the expenditure of no reagents. It should be quite obvious that microscopy was, in this instance, both a time and labor saver. But, the reader will say, an analysis of the coin was not really necessary, since its weight and "feel" pointed to the fact that it was spurious. All of which the writer admits, but the reader must remember that the archeologist had called for a chemical analysis so as to learn whether the coin was made of silver or of a base-metal alloy in order to settle the question as to its abnormal weight and "feel," and that he was given this information through a microscopic examination alone; an examination which required a mere glance at the magnified image.

Lest this case of the tetradrachm should be believed to be unique it can be asserted that there is a growing tendency in the industries to-day to submit at once to microscopic examination all metals and alloys which have proved defective or abnormal or whose compositions are in question. It is not so many

FIG. 1. MODERN COUNTERFEITS OF ANCIENT COINS.

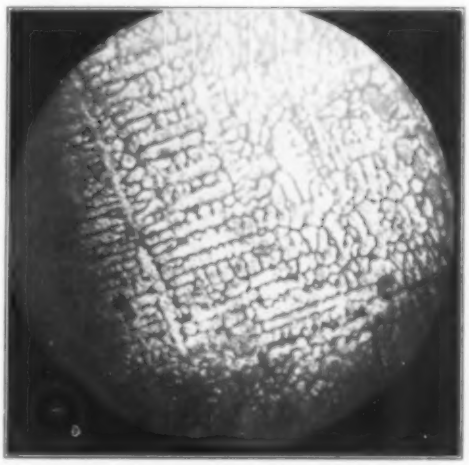


FIG. 2. HIGHLY MAGNIFIED SURFACE OF THE CENTRAL COIN IN FIG. 1.

years ago that in all such cases a complete chemical analysis would have first been called for as a matter of routine, under the belief that the abnormalities must be the result of peculiar chemical compositions. These analyses were often difficult and were time-consuming and expensive. Not infrequently upon their completion little or no light was thrown upon the problem at issue. Physical chemistry, the microscope and the pyrometer have revolutionized our ideas with the result that much time, labor and worry are saved by having recourse to routine chemical analyses only after

a microscopic examination has failed to completely solve the riddle. In the magnified image of a properly prepared alloy the expert is able to read a wondrous story.

But it is not only in the metallurgical industries that chemical analysis may prove to be unnecessary. It is now well recognized that the commercial success or failure of many products may depend largely upon the results of judicious microscopic studies of raw materials as well as of finished or partly finished products. These may be as far apart as milady's silk hose and the earth of a road to be surfaced with tar; or a "baby powder" and the pigment or filler entering into a rubber tire; or ore to be subjected to flotation and rosin for "size"; or a detergent or polishing powder and an abrasive wheel. Each and all, and a thousand and one more are being examined, studied and tested microscopically in order that qualities may be improved, production cheapened and sales increased.

Unfortunately, not all our firms have as yet come to realize the importance of these comparatively new methods, for example: a plant working a rock salt vein by forcing down water and pumping up the brine obtains a brine containing much calcium sulphate (gypsum). It was their custom to remove the calcium salt by adding a chemical which would precipitate it. There came a time when having lost their records and having no knowledge of the proper dosage they prepared a batch of salt and submitted a sample to a young chemist with the request that he determine whether or not all the gypsum had been removed and whether the product could be placed on the market as table salt. The chemist attacked the problem in the old orthodox manner: he determined the amount of chlorin, which he then calculated as sodium chlorid, the amount of calcium, which he calculated as calcium sulphate; the amount of sulphate ion, which he also calculated as calcium sulphate. But the two values he obtained for calcium sulphate did not agree. Puzzled, he consulted a more experienced fellow chemist, who remarked: "Before going over your figures let us see what the microscope will reveal.—— Look, my friend! Your sample must contain, I guess, not far from forty per cent. of gypsum." A photo-micrograph of this identical sample is shown in Fig. 3. The cubes and cubical masses are crystals of sodium chloride (common salt), the prisms and plates are the crystals of calcium sulphate (gypsum). A single glance through the microscope showed that the dosage had been insufficient and also enabled the observer to form an idea as to the quantity of impurity still present. This particular case is cited because it illustrates another advantage of microscopic methods, namely, that the process need not have been carried to completion and the salt separated from the brine. A small sample taken out during a run would have given in a few seconds all the information necessary. This is by no means an isolated case, but

FIG. 3. SAMPLE OF COMMON SALT CONTAINING GYPSUM.

is typical of what is being done more and more in the control of many diverse processes especially where a time factor enters or where it is desired to closely follow the progress of a reaction. In all such cases it suffices to remove small samples from time to time and submit them to microscopic examination. Where such methods are adopted instead of long solubility determinations or complicated analyses, the saving in time, labor and material may be relatively very great.

This does not mean that microscopic examinations are destined to displace or supplant the older, well-established, time-tried chemical control methods in the industries. Microscopic tests and estimates are often, at best, merely clever guesses. Yet they may be, with care, so very close to the truth that where an estimate only is needed and not an exact determination, it would be the height of folly for the analyst to overlook the economic possibilities of chemical microscopy.

Not infrequently a microscopic examination has shown at once that a preconceived hypothesis was completely wrong: a hypothesis that had been built up to explain phenomena or to account for low yields or for defects in manufactured articles. Here is a case in point. A run of smokeless powder was found on analysis to be too high in its ash content to pass inspection. The technical men of the powder plant built up a number of ingenious but wholly untenable hypotheses to account for the trouble. Much valuable time and money was spent in trying to uphold preposterous explanations which were contrary to common sense and mathematics. Had the powder-ash been examined under the microscope at once instead of after many days of fruitless discussion it would have been seen that the excessive ash was due to fine silt from dirty, improperly cleaned cotton. Of course, the trouble all started

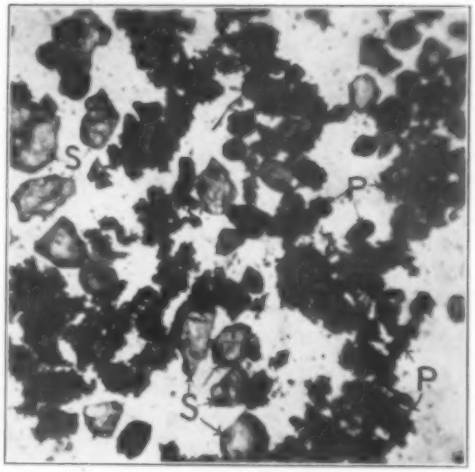


FIG. 4. ASH OF A PYROXYLINE POWDER CONTAINING SILT.

in bad sampling of the raw cotton and since the chemist's figures were wrong no one was convinced until the microscope revealed the true nature of the ash. In Fig. 4 we have a photograph of the ash of this rejected powder. The silt grains S, S, are easily differentiated from the normal ash P, P, of the pyroxylin. Were further confirmation deemed necessary the absolute identity of the minerals in this ash with those of the soil clinging to the cotton could very easily be proved, nay more the identity of the silt in the ash with that in the cotton field where the cotton was grown could also be established.

Let us now consider a very different sort of problem. The customers of a certain firm were approached by a representative of a competitor and told that the preparation which he would supply them for a certain purpose consisted of a single organic compound, while that which they had been buying consisted as they knew of two different compounds. Since his preparation had only one ingredient it stood to reason that its uniformity could be depended upon; but with two components, well! they could draw their own conclusions:

prices could be made right. The chemist of the firm originating the preparation surmised that the alleged single ingredient material was identical with theirs and in reality contained two compounds. Since the two compounds were very closely related substances and their identification in a mixture would be difficult indeed, he concluded that time and labor might be saved by having recourse to microscopic methods. He therefore laid his problem before a microscopist, who at once pointed out that the refractive indices of the crystals of the two compounds were widely different, no matter in what position the crystals might chance to lie; hence by selecting a liquid having the same index of refraction as one of the compounds and covering the preparation in question with this liquid, that particular compound would be practically invisible under the microscope while the other compound would stand out sharply and clearly. Not only could the two be thus easily differentiated, but the relative proportions of the two compounds in the mixture could be estimated without resorting to long and difficult analytical methods. Moreover, these results could be checked by making a second microscopic preparation using in this case a liquid having an index of refraction equal to that of the compound which had not been rendered invisible in the first experiment; under these conditions the second component of the mixture would become invisible while the first would be clearly defined and its amount readily estimated. That this procedure proved that the chemist was correct in his surmise the reader can judge for himself by consulting Fig. 5. This photomicrograph shows the material alleged to consist of but a single compound after it had been covered with alphamonobromnaphthalene. It will be seen that there are present crystals which have been rendered practically invisible, which have been marked "A" and that there are also crystals which stand out with well-defined contours, "B." It should be obvious that we have here proof that there are two compounds present and not one only.

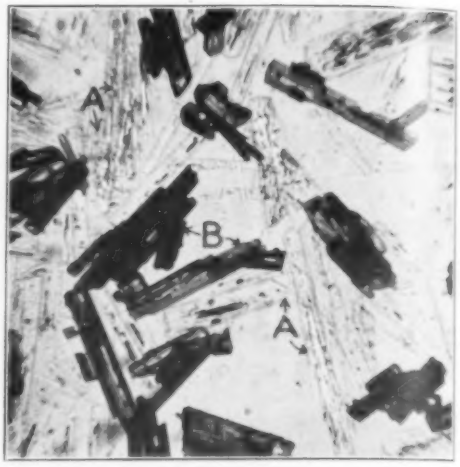


FIG. 5. DIFFERENTIATING BETWEEN TWO COMPOUNDS HAVING DIFFERENT REFRACTIVE INDICES.

Space will not permit a discussion of the methods employed for solving the other part of the problem, namely, proving the identity of the compounds in each of the two preparations, the original and the infringing one. Suffice to say that it was quickly and easily accomplished through the determination of the optical constants of the crystals of the compounds. It has taken as long to tell this little story as it does to make the tests and observations.

All these methods are very old and have been employed by mineralogists and petrologists for many years, but only recently has the chemist come to fully appreciate their value in qualitative analysis. By their use he is now able to rapidly ascertain the exact composition of most salts and of a great number of carbon compounds without the necessity of time-consuming quantitative analyses. Because he now employs only tiny amounts of material,

large samples are no longer essential and he has thus been rid, in large part, of his *bête noir*—the gathering of a sufficiently large sample to permit him to perform an analysis by the good old orthodox methods.

It is not possible to prove by photographs or other graphic methods that qualitative analysis by micro-chemical reactions is far more rapid than by the usual macroscopic test-tube reactions. The reader must take my word for it.

Rapidity is gained largely because small quantities are involved under relatively high concentrations, conditions which favor the rapid separation of the crystalline products upon whose formation the identification of compounds depends.

The space required for performing an analysis is very small. In Fig. 6 is shown an object slide upon which was made the analysis of an alloy corresponding in composition to that from which the coin shown in Fig. 1 was probably cast. A tiny fragment the size of the head of a small pin was dissolved and tested at "a," the supernatant liquid was decanted to "d" divided into several small drops, which were all tested by suitable reagents at "c" and "d." The photograph of the object slide was taken after the completion of the analysis. The alloy was found to consist of tin, bismuth and lead, with traces of copper, zinc and iron. The time required was thirty minutes, the cost of the material used was not over two cents and, as can be seen, the entire analysis was performed upon an area one inch square.

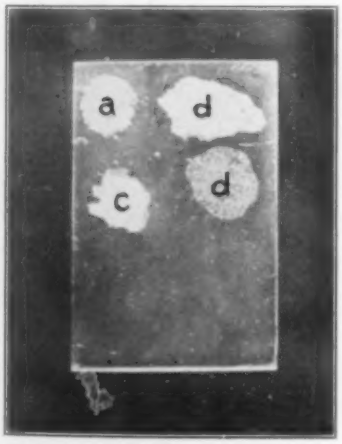


FIG. 6. A COMPLETE QUALITATIVE ANALYSIS PERFORMED UPON AN OBJECT SLIDE WITHIN AN AREA OF ONE SQUARE INCH.

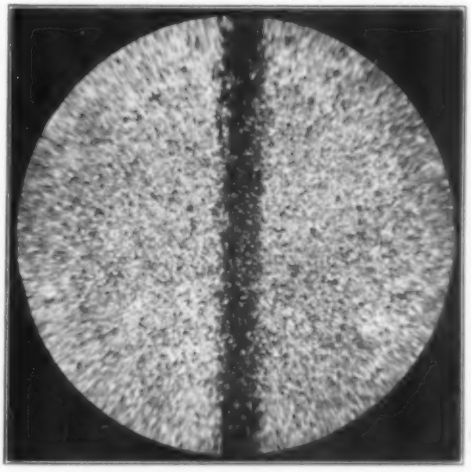


FIG. 7. OBTAINING A SAMPLE FOR ANALYSIS BY THE "STREAK" METHOD.

When small pieces or drillings may not be taken from a specimen for analysis, that is, it must not be injured in any way (as, for example, in the case of rare ancient coins, valuable archeological specimens, etc.), recourse is had to streak-sampling which has already been referred to above. This is accomplished by lightly drawing the specimen across the surface of ground-glass, unglazed porcelain or similar hard, slightly rough, material. A minute amount of the specimen is thus removed and clings to the rough surface, from which it can subsequently be removed by means of a suitable solvent. In Fig. 7 such a tiny streak has been magnified in order that it may be clear that such a procedure is in reality equivalent to filing off a sam-

ple and that an ample quantity of material has been obtained upon which to perform an analysis by microscopic methods. Unless a moderate magnification is employed, one can not discover where the specimen has been sampled and even then one can not be sure unless one knows beforehand just the precise spot which touched the abrading surface.

When streak-sampling is impracticable, the analyst removes infinitesimal quantities under the microscope, using for this purpose a variety of different sorts of tiny tools. Yet even in such cases it is impossible to detect where or how the sampling was accomplished. This may be fairly well illustrated by Fig. 8, in which is shown the "reverse" of a gold stater from Lampsacus, whose authenticity was questioned. The microscope showed that it was not a simple casting but had been either struck or hammered. A streak-analysis proved that it was of gold of a quality consistent with an ancient origin. The patina in the depressions in the coin was seen to be abnormal and under moderate magnification had every appearance of having been applied with a brush. An infinitesimal amount was removed under the microscope and on analysis was found to consist of gum, starch, coloring matter (a water color) and a very little fine silt; a very cleverly imitated patina. In the figure the coin is shown, magnified, before and after the removal of sufficient "patina" for the analysis. The removal was made at the spot indicated by the white arrow, "R." Even a careful scrutiny of the two photographs will fail to disclose any evidence of sampling.

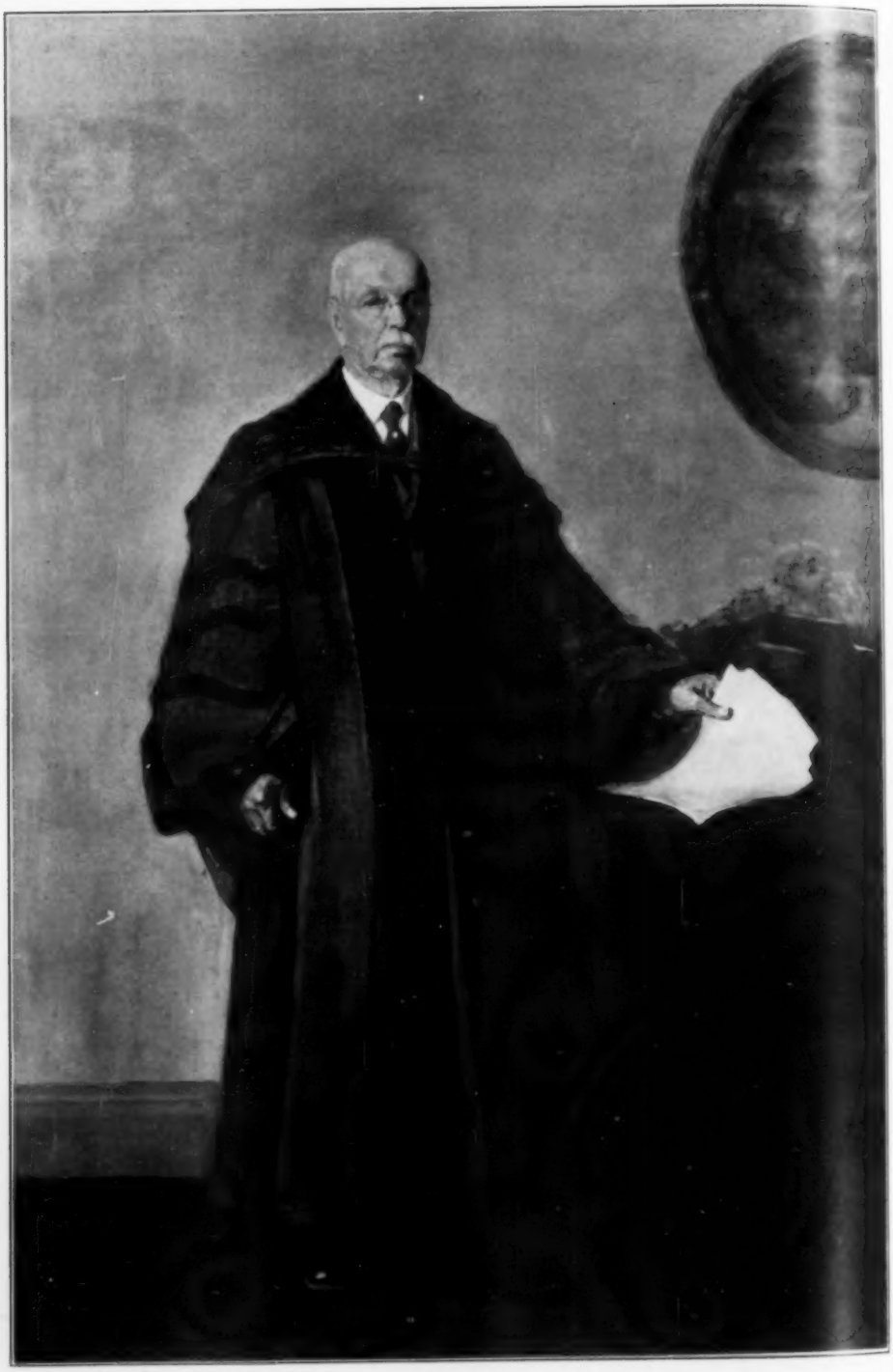
The few examples of the efficacy of microscopic methods which have been discussed in this article are each typical of many analogous cases which have been successfully attacked by similar procedures. They have been selected because of their simplicity. Complex qualitative analyses are being dealt with more frequently by more complicated optical-crystallographic methods whenever the chemists have the necessary training and experience.

The proof that these methods are regarded as important and essential is evidenced by the establishment of schools of microscopy and the announcement of one department of chemistry after another in our universities that instruction will be given in micro-chemistry.

FIG. 8. MODERN COUNTERFEIT OF AN ANCIENT GOLD STATER, BEFORE AND AFTER ANALYSIS.

FIG. 9. LABORATORY OF INTRODUCTORY CHEMICAL MICROSCOPY, DEPARTMENT OF CHEMISTRY, CORNELL UNIVERSITY.

Cornell University was one of the pioneers in this field: as long ago as 1900 courses for undergraduates were offered in microscopic qualitative analysis. From a small laboratory accommodating at first only four students, there has developed the magnificently equipped room shown in Fig. 9, together with three other laboratories devoted to special microscopic investigations. Evidently chemical microscopy, the time and labor saver of the chemist, has come to stay in industrial and in research laboratories, both at home and abroad.



IRA REMSEN

PROFESSOR OF CHEMISTRY IN THE JOHNS HOPKINS UNIVERSITY SINCE ITS FOUNDATION IN 1876 AND SECOND PRESIDENT OF THE UNIVERSITY. THIS PORTRAIT OF DR. REMSEN WAS PAINTED BY HIS SON, AT WHOSE HOME IN CALIFORNIA HE DIED ON MARCH 4.

THE PROGRESS OF SCIENCE

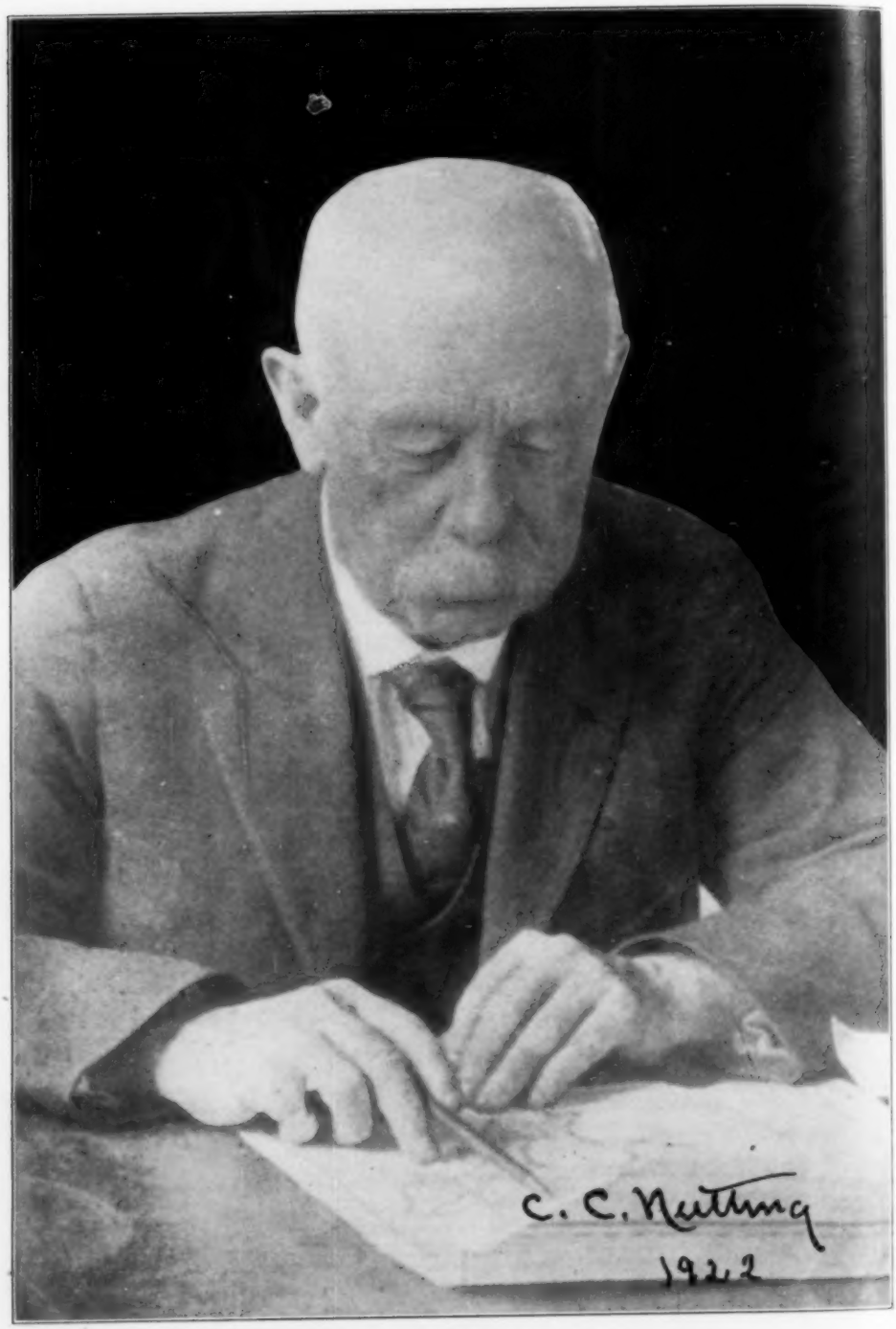
EDITED BY DR. EDWIN E. SLOSSON
Director of Science Service

NATURE'S NOTEBOOK

BY DR. FRANK THONE
Science Service Staff Writer

"CHEER-UP! Cheer-up! Cheer-up!" The most incurable optimist in the world is the robin. He comes shouldering his way through the roughest March wind, proclaiming obstinately that spring is here, and he'll keep on proclaiming it through a whirling snowstorm, or until a hailstone big as the proverbial hen's egg hits him on the head. He hasn't any sense at all, and that's why we like him. You can't convince an American, of course, that a robin isn't a robin; but actually, as a fine point in ornithology, our robin is a thrush. The early English colonists were very fond of the English robin, a smaller bird but with a brighter breast, and belonging to a somewhat different family, and when they settled on this side of the Atlantic they transferred the name to the red-breasted bird they found here, regardless of the fact that when "the north wind doth blow" he does not "hide in a barn to keep himself warm" but migrates southward below the severe frost line. But now our robin is a robin to all of us, and we defy any one to take away his name as he would defy any one to take away his worm. How the robin finds worms under the ground has been a standing riddle to naturalists for generations. He certainly can't see them, and it is hardly likely that he can smell them; yet when he makes the dirt fly furiously for a minute he almost always ends up with a one-sided tug of war with a worm. The best guess seems to be that his ear is so unbelievably keen that he can hear the faint rasping sound an earthworm makes in its burrow. The fact remains that he does get it!

WE are accustomed to treating the skunk as a somewhat shady joke; somehow everything that has to do with the sense of smell seems to be comic to most people; poor Cyrano was the only mortal to whom a nose was not funny. So we run when we see a "woods pussy," and indulge in persiflage about him afterwards. But really, our humor about the skunk is somewhat misplaced. He is himself as serious as a Scotchman, and as thoroughly given to minding his own business and letting other folk mind theirs. Only when he is interfered with does he unlimber his one potent means of defense. That is something not to be used for a trifle, because chemical warfare, whether waged by man or beast, is expensive. It takes a lot of feeding to distil a sacful of mephitic extract. So if you let him alone you are in no danger from him. And if you let him alone he will do you many a good turn without your ever knowing about it. For the skunk, like all the rest of his kin of the weasel tribe, is a tireless hunter of vermin. Rats and mice and such small deer are his principal food, but he does not despise succulent beetles and other good sized insects that prey upon our crops and timber. True, he sometimes forgets his manners so far as to rob a henroost, and frequently also he pounces on our friends the toad and the frog; but the evil that he does is more than outbalanced by the good. Finally, skunks somehow lose their terror when they depart this life—in a hurry and much against their wills—to become furs for milady. Formerly this handsome black-and-white pelt had to be sold under vari-



CHARLES CLEVELAND NUTTING

CURATOR AND PROFESSOR AT THE IOWA STATE UNIVERSITY SINCE 1886, IN WHOSE DEATH ZOOLOGY SUFFERS A SERIOUS LOSS.

ous aliases, but now we have the courage of our desires (if we have the purchasing power to back it), and in coat or neckpiece we are willing to call a skunk a skunk.

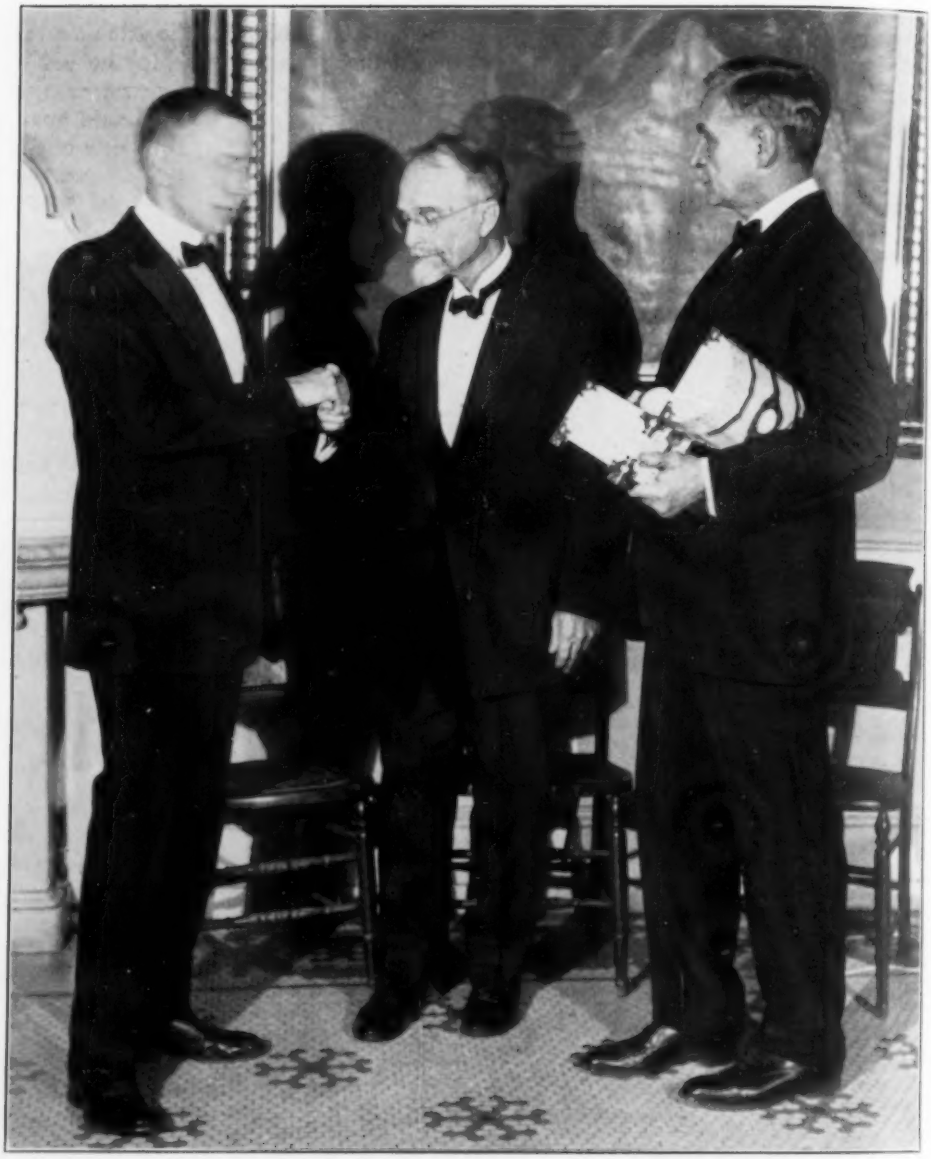
A GENERATION ago, muskrat furs were not held in very high regard; to-day, with the supply of the more precious peltries of the Canadian high north becoming depleted and the Siberian supply seriously interfered with by the effects of political revolution, muskrat has become a valuable staple in the fur market. So much so, indeed, that muskrat "farming" is taking its place among our industries, along with the farming of the highly expensive silver fox and the rigidly protected sealeries of the Pribilof Islands. Muskrat farming, however, partakes more of the nature of protected and systematized trapping on private preserves than it does of the exploitation of fairly well domesticated animals like the fox. The principal commercial muskrat area is in the vast swamps of the Gulf edge of Louisiana, where great private holdings of the almost valueless land (if it can be called land) are parcelled off and leased out or sold to the trappers. These men know from experience how much trapping a given piece will stand without being depleted, and practise conservation of the animals for the benefit of their own business. This profitable fur-raising industry is coming into embarrassing conflict with the program of sanitary engineers working against the mosquito pest in the South. The engineers want to drain the swamps to relieve the cities and the upland farms of the swarms of plaguing, and frequently malaria-bearing, mosquitoes. The muskrat farmers naturally want the swamps left alone, for their living depends on them. A *modus vivendi* between the two interests is now being sought.

THE early bird may get the worm, with our entire approval; but the early fly should get it in the neck. A stitch in time saves nine; a swat in time may save nine million. Now is the time for all good housewives to come to the aid of their country with the fly-swatter. Or if they can not find it, they should hurry to the corner store and get a new one at once. The very first flies, the ones that have survived the winter furtively hiding in odd corners in a semi-dormant condition, are the ones at which the first drive of eradication should be directed. It used to be thought that these were harmless, but the Department of Agriculture now states that they are capable of propagating their evil breed, and therefore should be regarded as enemies. Of course, the swatter is of avail only domestically. The early campaigns for the stopping of the fly pest should hunt for their source of supply, which is almost solely the manure piles of stables, and the drive should not be stopped short of seeing these cleaned up, and all unavoidable litter kept in covered pits or bins and sprayed with kerosene or sprinkled with lime. There is little excuse for fly-breeding places in cities any longer, with the ever-decreasing urban use of horses. On the farm, where livestock is still a prime necessity, their presence may be looked upon as an evil, unavoidable perhaps, but none the less not to be tolerated beyond the most irreductible of minima.

PRETTY pussies down by the brook,
Swinging away to and fro
On the bending willow boughs,
Like pussy cats all in a row!

If I put you down by the fire,
You pussies so cunning and shy,
I wonder if you'd turn
Into pussycats bye and bye?

Who does not remember this old song, which we all learned during March of that memorable first year in school? Even to the keen regret we all experienced—and it lingers in most of us still—that the little gray catkins held loyally to their duties as pussy-cats to the fairy



PRESENTATION TO DR. CHEVALIER JACKSON

PROFESSOR JACKSON, OF THE JEFFERSON MEDICAL COLLEGE, IS RECEIVING FROM SENATOR PEPPER, OF PENNSYLVANIA, THE BOK PHILADELPHIA AWARD FOR PUBLIC SERVICE, CONSISTING OF A GOLD MEDAL AND TEN THOUSAND DOLLARS. THE AWARD WAS MADE FOR DR. JACKSON'S WORK WITH THE BRONCHOSCOPE.

folk? Like many other things that come on very early in the spring, when frosts still come every night and snow may come any week, pussy-willows do seem to belong to another world. In a sense they do belong to another world, even to the cool and factual eye of science. Their season with us is the season of barely melting ice; these strange flowers blossom and shed their pollen and achieve fertility and form their seeds, all before the bees, and the bright-petaled blossoms that depend on the bees, are abroad at all. Willows can thrive and reproduce in a world without insects; the cold wind is duenna enough for their love-making. A world without insects? Well, such a thing obtained, at least locally, fifty or a hundred millenniums ago, along the edges of the ice sheets of the Glacial Epoch. That there were willows there then can hardly be doubted. Willows now push their advance to the edges of the polar ice cap and to the snow line of our high mountains, and willow remains are thick in the bogs left by the retreat of the glaciers. Whatever gnomes or kobolds the days of the Long Cold knew had at least the comfort of little furry tabbies lined on twigs.

Among the very earliest of showy cultivated flowers, almost as early as the pussy-willow and the skunk cabbage, is the crocus. It hardly waits for the snow to melt off the lawn before it pushes its sudden bright blossoms up through the short, crisp green grass. It seems a bit queer to find these big flower-stars scattered about, with never a leaf to account for them. For the leaves mostly come only after the flowers have gone, and look so much like big grass blades themselves that few of us pay much attention to them. The answer is that the flowers do not depend on the leaves. Obviously they can not, for if they did they would constitute a case of the effect preceding the cause. They do depend on leaves, but the leaves are the ones that grew last year, and formed the starchy corm, the thick, onion-shaped storage organ underground that feeds its substance up into the sun-seeking flower. Though commonly called a bulb, this foundation of the crocus is not a bulb in the strict sense of the word, and therefore it gets another name. Onions are true bulbs, and lilies and tulips, which are closely related to onions, also spring from bulbs. If you cut an onion in two you will see that it is formed of layer upon layer of thick, fleshy scales, which are really leaves specially modified to store up food. But the corm of a crocus does not show this layer-arrangement if it is cut. It is solid clear through, and the leaves are represented only by lines or scars on its brown outside. It performs the same service, but its build is different, so it gets a different title.

THE BICENTENNIAL OF NEWTON'S DEATH

The twentieth of March of this year is the two hundredth anniversary of the death of one of the greatest scientific men of all time—Sir Isaac Newton. His long life of eighty-five years comprised many different activities. As a young man he practised alchemy. He wrote many theological treatises; he was a professor at the University of Cambridge, and for the last thirty years of his life he was the master of the British Mint. But upon none of these does his fame rest. Hundreds of men have equalled or exceeded Newton in such respects, and all have been swept by relentless time into the limbo of mediocrities.

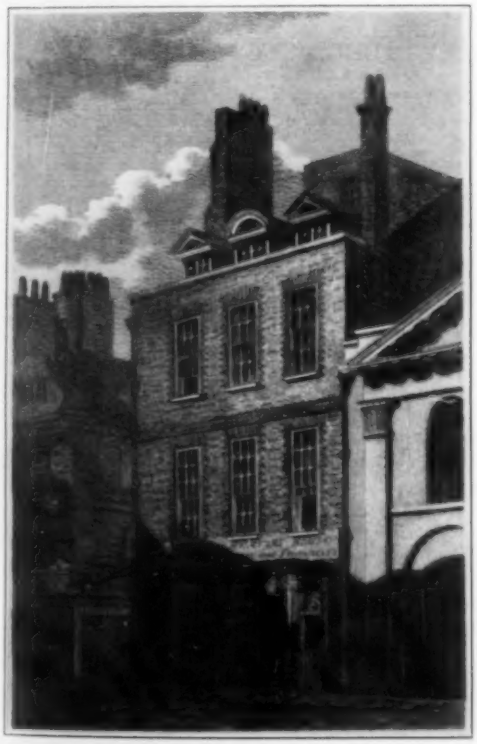
Why is Newton remembered? Not primarily for his experimental work in optics, important as this is, for a dozen others have done as well. Not because

SIR ISAAC NEWTON

he "discovered gravitation"; that had been known since the days of Aristotle. Not because he formulated the exact law according to which gravitation acts, for that appears to have suggested itself to at least three of his contemporaries. Not that he was the first to conceive the idea that the earth's gravitative attraction might reach as far as the moon; that had been imagined before him, though no demonstration of it had been given.

Newton stood head and shoulders above his contemporaries because he had vision, a broad mental grasp, a good sense of perspective. Scientific knowledge before his day consisted chiefly of isolated facts of observation, with little or no correlation, and no satisfactory assigned causes. But Newton was able to visualize all the moving bodies in the universe from comets to falling apples, and to demonstrate that they all obeyed a single law—universal gravitation. He brought order out of chaos; he had constructive talent; he was a builder, not only a collector of building materials. It was nearly two hundred years after the publication of the "Principia" before the scientific world saw its like, until Darwin, with the "Origin of Species,"

WOOLSTHORP MANOR HOUSE, THE BIRTHPLACE OF ISAAC NEWTON



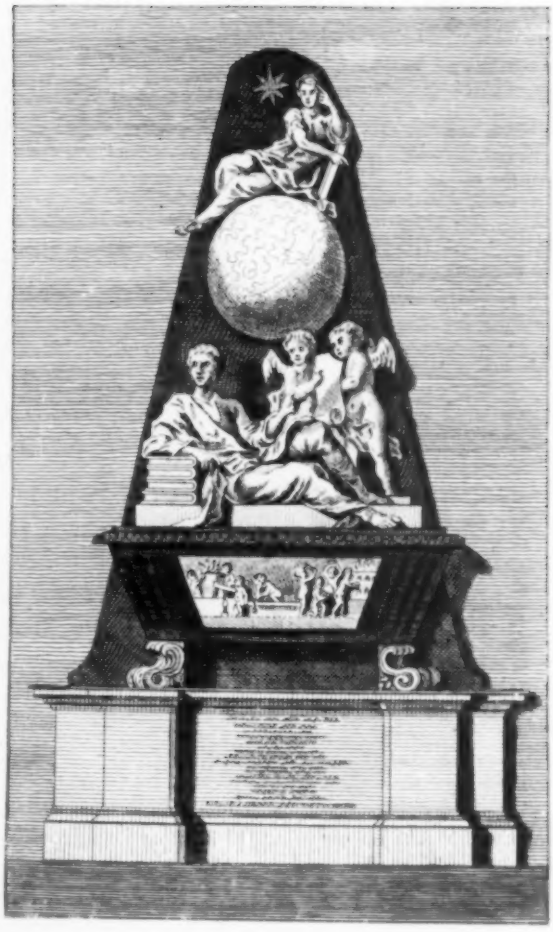
THE RESIDENCE OF NEWTON
ST. MARTIN'S STREET, LEICESTER FIELD, LONDON

did for biological science what Newton had done for physical science two centuries earlier. Such men are rare, but scientific progress would be impossible without them.

How thoroughly Newton accomplished this task is evidenced by the change in scientific thought since his day. The "Principia" is taken for granted; the picture of the universe set forth in it is part of our common heritage, almost innate. Newton succeeded in endowing all scientific posterity with a measure of that vision and perspective which he alone possessed in his day. He said modestly of himself: "If I saw farther, 'twas because I stood on giant shoulders." But by the hands of Newton we have been lifted and placed upon a peak which he himself could not reach, from which, like Moses of old, we may look over the Promised Land, though it may be reserved for those who follow us to enter.

This appreciation of Newton's great constructive contribution to modern science has been prepared by Dr. Paul R. Heyl, of the U. S. Bureau of Standards. For most people Newton's name is iden-

ISAAC NEWTON



INSCRIPTION ON NEWTON'S TOMB IN WESTMINSTER ABBEY

HERE LIES
SIR ISAAC NEWTON, KNIGHT,
WHO BY A VIGOR OF MIND, ALMOST SUPERNATURAL,
FIRST DEMONSTRATED
THE MOTIONS AND FIGURES OF THE PLANETS,
THE PATHS OF THE COMETS, AND THE TIDES OF THE OCEAN.
HE DILIGENTLY INVESTIGATED
THE DIFFERENT REFRANGIBILITIES OF THE RAYS OF LIGHT
AND THE PROPERTIES OF THE COLORS TO WHICH THEY GIVE RISE.
AN ASSIDUOUS, SAGACIOUS, AND FAITHFUL INTERPRETER
OF NATURE, ANTIQUITY, AND THE HOLY SCRIPTURES,
HE ASSERTED IN HIS PHILOSOPHY THE MAJESTY OF GOD,
AND EXHIBITED IN HIS CONDUCT THE SIMPLICITY OF THE GOSPEL.
LET MORTALS REJOICE THAT THERE HAS EXISTED SUCH AND SO GREAT
AN ORNAMENT OF THE HUMAN RACE.
BORN 25 DEC., 1642; DIED 20 MARCH, 1727.

tified with the theory of gravitation. Legend has it that his attention was forcibly called to gravitation by the fall of an apple upon his head as he rested beneath an apple tree. Voltaire is the authority for this anecdote and he is said to have obtained his information from Newton's favorite niece. But whether the apple legend is true or untrue, it is a fact that Newton's thoughts and researches upon gravitation have changed our conceptions of the universe. He began his researches when a lad of but twenty-four years; in 1665 and 1666 when the plague had driven him and all other students from Cambridge, Newton said: "I was in the prime of my age for invention, and minded mathematics and philosophy more than at any time since."

The great Galileo died the year Newton was born and it was his invention of the telescope and his planetary observations that prepared the way for Newton's discovery. John Kepler, follower of the master astronomer, Tycho Brahe, had reduced to simple laws the movements of the planets, most important of which was the fact that they moved in elliptical orbits around the sun at one of the two foci. Why should a planet swing a closed orbit around the sun instead of shooting off in a straight path? The mathematical genius of Newton proved that if there existed an attracting force between the sun and the earth that varied inversely proportional to the square of the distance between the two bodies, the earth would sweep the identical orbit around the sun that Kepler had observed. Experience with falling bodies and the weight of things suggested that the earth attracts bodies far from it just as it attracts a falling stone. Again Newton's calculations proved his theory right and the moon was shown to be but an immense stone ever falling toward earth and so kept in its orbit. The earthly force of gravity became a heavenly force as well.

Newton said: "I do not know what I may appear to the world; but to myself I seem to have been only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me."